Typical structures using TurnaSure DTIs

LEFT:
Torre Repsol Tower Project  Madrid, Spain

CENTER:
KLCC Towers  Kuala Lumpur, Malaysia

RIGHT:
Hoover Dam River Bridge  Arizona & Nevada
A Proven Technology
Originally established in 1805 as gun manufacturers, the Turner Companies later developed fastening systems. They have been pioneering the design, manufacture, and use of this simple, accurate, and cost effective method of inspecting proper bolt tension for over thirty five years. In 1962, the first ‘Coronet Load Indicator Washer’ was introduced. Today’s re-engineered versions are known as ‘Direct Tension Indicators’, DTIs or ‘Tension Indicating Washers’. DTIs are specially produced washer-shaped devices with protrusions pressed out on one face.

Accepted by AISC, ASTM, AASHTO and FHWA
TurnaSure LLC, (J & M Turner) has been manufacturing DTIs to ASTM F959 since the origin of that standard in 1985, and continues to be the world leader in production and supply of DTIs for structural projects worldwide. TurnaSure now manufactures a full range of metric sizes to ASTM F959M, Types 8.8 and 10.9. TurnaSure’s DTIs have been accepted not only on ASTM A325 and A490 bolts, but also on projects using Japanese JISB 1186F10T (10.9), British BS 4395, and other worldwide standards. These applications include a diversity of major steel structures, ranging from the world’s tallest buildings, major bridges, military structures, the Space Shuttle Launch Pad, Refineries, and other industrial and commercial steel structures.
How TurnaSure DTIs work

The DTI is placed on a bolt with the protrusions bearing against a hardened surface on the bolt-nut assembly. The preferred assembly is under the bolt head as shown in figure 1. Note the obvious gap between the DTI and the bolt head.

As the bolt and nut are tightened, the clamping force flattens the protrusions and reduces the gap. When the gap is reduced to the required dimension, the bolt is tensioned to specification. (See table 1).

Inspection is performed quickly and easily. Simply check a few bolts with the supplied metal feeler gauge used as a 'no-go' inspection tool. An easy visual inspection will verify that all the adjacent bolts have also been properly tensioned.

Why were DTIs created?

DTIs curb the deviations in other tightening methods

Wide variances in bolt tensions are frequently experienced with other permitted methods; for instance:-

Turn of nut method

Turn of nut requires a given value of initial tension present in a bolt (10%), after the plies have been fully snugged. Whereas this ‘start point’ is easily gauged in a bolt tension calibrator, it is impossible to gauge this all important start point in the field. There is absolutely no possible measure of this. If the connection is not properly snugged, often requiring much more force than ‘the full effort of a man with an ordinary spud wrench’, then the subsequent turn will fail to stretch the bolt above the required tension.

Different degrees of turn are necessary after the vagaries of the ‘snugging’ operation. These depend on the length, diameter, or grade of fastener. Without precise match marking, there is absolutely no knowledge of whether or not the required amount of turn was ever executed... and subsequent torque inspection cannot verify induced tensions!
DTIs curb the deviations in other tightening methods

'Twist-off-bolts' and Calibrated Torque Wrenches.
Torque control does little more than measure twist or turning forces. Even if the torque wrench is accurately measuring torque, or the end of the twist-off-bolt accurately breaks off at the same torque, torque measurement is still entirely at the mercy of lubricity. Torque can never do more than measure this friction in the bolt threads, (approximately 40% of applied torque), or on the nut face, (approximately 50%). The dryer the bolt, the smaller proportion goes into the effort of producing tension. Numerous research studies on torque or twist-off-bolts show wide variations of induced tensions. From ±30%, even in the "as received condition", to well above ±50% in "field conditioned samples", (to three sigma).

Twist-Off bolts tested at Bucknell University from a job-site in New Haven, Connecticut, USA

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Bolt Tension, Kips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>15.0</td>
</tr>
<tr>
<td>2.5</td>
<td>12.5</td>
</tr>
<tr>
<td>5.0</td>
<td>10.0</td>
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<tr>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>12.5</td>
<td>2.5</td>
</tr>
<tr>
<td>15.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum Bolt Tension 28 Kips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension in 3/8 Inch TC bolts</td>
</tr>
<tr>
<td>Mean = 29.1 Std Dev = 4.2</td>
</tr>
</tbody>
</table>

Under Tension
The benefits of specifying DTIs

TurnaSure’s Direct Tension Indicators are an inspection tool to show unequivocally that the bolt has been tightened to tensions that are above the minimum required. It is that simple. Whatever method is used to tighten the bolt, the DTI shows that the proper tension is present in the installed bolt assembly.

Assurance of slip resistance.

All connections deemed slip-critical must not slip. Structural engineers take into account the particular slip factor for the various joint surface conditions. They design for a clamping force that will prevent a particular connection from slipping at service loads. DTIs guide the installer to tension the bolts to above their minimum specified tensions. (See table 1)

Control of cyclical stresses.

It is very important to make certain on connections subject to cycles of stress along the bolt axis, that the applied force is always significantly lower than the clamping force. DTIs assure the required clamping force is present in the connection. If applied loads are greater than the clamping force, bolts will loosen or fail by fatigue. The maximum permitted stress cycle is 60% of the required minimum bolt load. For infinite endurance under such cyclical stress, the bolts must be installed at, or better still, above the minimum tension. (see table 1).

How to specify - All A325 and A490 (or A325M and A490M if metric) High Strength bolts shall be tightened and inspected using Direct Tension Indicators to the latest revision of ASTM F959 or F959M. Only TurnaSure DTIs or licensees accepted.
The benefits of specifying DTIs

Minimise the effect of prying action.
Properly tensioned bolts sense very little change in stress under prying loads. The presence of a DTI has been shown by research to inhibit permanent loss of bolt pretension when the connection is subjected to high prying action. The fatigue life of fasteners is improved by the minimisation of prying action and the maximisation of bolt preload. Studies have shown that a connection that developed little or no prying force is preferable under repeated loading.

Improved structural rigidity.
Properly tensioned fasteners will absorb energy and dampen a structure against movement caused by wind or seismic loading. DTIs benefit structural rigidity and integrity by ensuring properly clamped connections.

Confirm bolt-nut conformance and compatibility.
By indicating a bolt is installed beyond the minimum required tension, a TurnaSure DTI has also tested the quality and compatibility of the bolt-nut assembly. It shows that the lubrication was satisfactory, that the nut did not strip or ‘freeze up’ during the tightening process, and that there was no significant plastic yielding of the bolt due to substandard material.
The benefits of specifying DTIs

*Detect trapped bolts.*

Placed under the head of a long bolt in a connection with multiple plies, the DTI can and has detected trapped bolts. Trapping is usually caused by premature release of steel sections onto the untightened bolt shanks. The inability to compress the DTI showed the bolt could not be pulled through the holes, and the installed fasteners could not clamp the connection together. Holding steel in place until after fully tightening bolts is necessary particularly with multiple plies.

*An aid to iron workers.*

*An aid to snugging* - DTIs are the only method which offer visual proof that snugging of the plies has been accomplished. By only partially compressing the protrusions, half the minimum required tension has been induced. This method should generate far superior snugging forces when compared with 'the full effort of a man using an ordinary spud wrench'.

*An aid to final installation* - Due to the improved predictability and enhanced accuracy of TurnaSure DTIs, iron workers are successfully judging the gaps by eye. There is now so little variation in the DTIs themselves, the crew simply stops tightening when the gap looks right. Due to lower protrusion profiles, tightening is quicker. A quick look at the DTIs after assembly is all that is necessary. All this without expensive ‘callbacks!’

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Advantages of the redesigned TurnaSure™ DTIs

The following benefits surpass all other DTI designs worldwide.

*Patented technology.*

Each of TurnaSure’s DTIs are covered under two or more of the following four US patents:

*Patent number #5,015,132.*

All our DTIs are covered by this patent which provides the following benefits:

1.) It enables the protrusions to be compressed without being affected by rust, lubrication or coatings as the pockets on the underside of the protrusions are larger than the actual protrusion. Either the pocket or the protrusion walls can be angled (see illustration below). This results in ‘Friction Free Push Back’™.

2.) Another benefit is that this feature always allows the protrusions to be fully compressed to nil gap. Conventional DTIs have pockets that are sometimes significantly smaller than the protrusion. In being pushed back, the protrusions can sometimes spread like a pancake, and can therefore never be fully compressed. This can impede efforts to flatten DTIs.

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Advantages of the redesigned TurnaSure DTI

No need to use hardened washers when tightening under turned element.

During the development of DTIs for SAE bolts and nuts, it was discovered that the new curved protrusions negated the need for a hardened washer to be sandwiched between the DTI and the turned element. This instruction is included in SAE standard J2486. An independent research carried out at Laboratory Testing in Hatfield, Pennsylvania, USA, showed that with the new curved protrusion structural DTIs there is even improved consistency when not adding the hardened washer between the DTI protrusions and the turned element (nut). Field-testing has also been demonstrating that the hardened washer can be eliminated when tightening these TurnaSure DTIs directly under the turned element. (See assembly illustrations on page 13 and the new TurnaSure field instructions on DTI use, which also notes that special washer requirements for short slotted and oversized holes must still be followed.)

Production lots certified in independent accredited laboratory.

Samples of production lots of DTIs are tested by Laboratory Testing Inc., (LTI), a leading independent testing laboratory. LTI is accredited in the field of DTI testing by the American Association for Laboratory Accreditation (A2LA). All these tests are traceable to the National Institute of Standards and Technology. Compression load testing is performed using a Digital Compression Load Analyser equipped with a high resolution dial gauge. Testing is conducted in accordance with the guidelines of Annex A1 of the American Society for Testing and Materials (ASTM) specification ASTM F959.
What the redesigned TurnaSure DTIs look like

ASTM Grade marking.

Lot number for lot sizes up to 250,000 pieces allow for permanent traceability of installed parts to all original manufacturing and test data.

Patented protrusion pockets assure consistency regardless of surface condition. **Friction Free Push Back™**

Indents assist in fast & easy inspection.

TurnaSure Trademark symbol of most accurate system on market (±1% accuracy).

New curved protrusions for superior fit under bolt heads and perfected reliability. Now eliminates hardened washers when tightened under turned element (see Note A opposite).

Availability of TurnaSure’s DTI

**Available in plain (un coated) finish:**

For A325 Type 1 bolts in diameters from ½” through 1¼”.

For A325M (8.8 strength) bolts in diameters from M12 through M36.

For A490 Type 1 bolts in diameters from ¾” through 1¾”.

For A490M (10.9 strength) bolts in diameters from M12 to M36.

**Note:** The metric DTIs are also compatible with foreign bolt standards including JISB 1186 F10T - Japanese Standard.

**Available in Mechanically Galvanised finish (to ASTM B 695 Class 5C).**

For A325 Type 1, or ASTM A325M, Hot Dip or Mechanically Galvanised bolts in diameters ½” through 1¼”, and M12 through M36.

**Available in Weathering Steel.**

For use with A325 Type 3, or ASTM A325M type 3 bolts in diameters from ¾” through 1½” or M12 through M36.

In addition TurnaSure manufacture Tension Indicating Washers in a full range for SAE Grade 5 and Grade 8, and Class 8.8 and 10.9 cap screws. They are also produced for studs on gasketed flanges and for numerous other special applications.

**Note:** All TurnaSure DTIs are manufactured in the USA.

How to specify - All A325 and A490 (or A325M and A490M if metric) High Strength bolts shall be tightened and inspected using Direct Tension Indicators to the latest revision of ASTM F959 or F959M. Only TurnaSure DTIs or licensees accepted.
How to specify TurnaSure DTIs

Direct Tension Indicators must usually be specified to make certain they are included in the project specifications. The specification is simple and should read as follows:

All A325 and A490 (or A325M and A490M if metric) High Strength bolts shall be tightened and inspected using Direct Tension Indicators to the latest revision of ASTM F959 or F959M. Only TurnaSure DTIs or licensees accepted.

When requiring Weathering Steel DTIs (for type-3 bolts) add:

'Direct Tension Indicators (DTIs) for use in weathering steel shall meet all the requirements of ASTM F959 or (F959M). In addition, such DTIs shall be manufactured from steel conforming to the chemical requirements of ASTM F436 for type 3.'

How to Install TurnaSure DTIs

Full installation instructions are available in TurnaSure's instruction manual known as the "little red book." There is one book each for either inch or metric. Please email or call for a copy. Also, each shipping carton includes instructions and feeler gauges. Instructions are also available in several foreign languages upon request.

DTIs are installed in the following three ways - illustrated below.

Method 1 - DTI under the head - Turn the nut to tension.
Should be used whenever possible as it ensures that the bolt has not been trapped by movement of the steel plies before tightening. The other methods 2 and 3 are suggested but should only be used when Method 1 cannot be.

Method 1
(Preferred method)
DTI under head - Turn nut to tighten, bolt head held.

Method 2
DTI under the nut - Turn the nut to tension.

Method 3
DTI under the bolt head - Turn the bolt head to tension.

Bevel washers
DTIs can also be used with bevel washers to accommodate over a 1:20 bevel.

Note A: The new TurnaSure DTIs no longer need hardened washers sandwiched between the nut and DTI protrusions. This assembly was for DTIs with the older design "straight-sided" protrusions. With the old design DTIs a hardened washer has to be used between the nut and DTI to achieve consistent assembly loads.
## How to inspect TurnaSure DTIs

Detailed inspection is covered in the ‘Little Red Book’

**Use feeler gauge and compare adjacent DTI gaps by eye.**

Use the correct thickness feeler gauge—either 0.015” or 0.005” or if using metric bolts 0.4MM or 0.125MM as a “no-go” inspection tool. (See table 2)

When using feeler gauges, to get a true reading, one should try to insert the pointed end of the feeler gauge into the opening between adjacent, flattened protrusions. Inspection is based on the average gap. To measure this, simply make certain that the gauge is refused in more than half of the spaces. Minimum number of refusal spaces are shown in table 1 below. Zero gap is acceptable.

### Table 1 (inch)

<table>
<thead>
<tr>
<th>Bolt Size (In.)</th>
<th>Minimum bolt tension (kips)</th>
<th>DTI spaces</th>
<th>Minimum gauge refusals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A325 A490</td>
<td>Type 325</td>
<td>Type 490</td>
</tr>
<tr>
<td>⅛”</td>
<td>12 15</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>⅜”</td>
<td>19 24</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>⅝”</td>
<td>28 35</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>⅞”</td>
<td>39 49</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>1”</td>
<td>51 64</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>1¼”</td>
<td>56 80</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>1½”</td>
<td>71 102</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>1½”</td>
<td>85 121</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>1⅝”</td>
<td>103 148</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

### Table 1 (mm)

<table>
<thead>
<tr>
<th>Bolt Size (mm.)</th>
<th>Minimum bolt tension (kN)</th>
<th>DTI spaces</th>
<th>Minimum gauge refusals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A325M A490M</td>
<td>Type 8.8</td>
<td>Type 10.9</td>
</tr>
<tr>
<td>M16</td>
<td>91 114</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>M20</td>
<td>142 179</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>M22</td>
<td>176 221</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>M24</td>
<td>205 257</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>M27</td>
<td>267 334</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>M30</td>
<td>326 408</td>
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<td>8</td>
</tr>
<tr>
<td>M36</td>
<td>475 595</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

### Table 2 DTI Gaps

<table>
<thead>
<tr>
<th>DTI fitting</th>
<th>DTI spaces</th>
<th>Minimum gauge refusals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 325</td>
<td>Type 490</td>
</tr>
<tr>
<td></td>
<td>Type 325M</td>
<td>Type 490M (10.9)</td>
</tr>
<tr>
<td>Under bolt head plain finish DTIs</td>
<td>0.015”</td>
<td>0.015”</td>
</tr>
<tr>
<td>Mechanically galvanized DTIs</td>
<td>0.005”</td>
<td>-</td>
</tr>
<tr>
<td>Weathering Steel DTIs</td>
<td>0.005”</td>
<td>-</td>
</tr>
<tr>
<td>Under turned element (plain finish)</td>
<td>0.005”</td>
<td>0.005”</td>
</tr>
</tbody>
</table>

The technical reports and research papers described opposite are available from TurnaSure.

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Corrosion.

For painted structures
Two test specimens of steel plates, each bolted together with DTIs, were submitted to Mellon Institute in Pittsburgh, Pennsylvania for a test on corrosion, and possible moisture ingress into the spaces between the protrusions.

The test specimens had been painted with $2\frac{1}{2}$ mils of zinc rich primer and 4 mils of vinyl top coat typical of the paint systems used in bridge applications. The specimens were subjected to over 1,000 hours in a salt fog resistance test following ASTM B117 protocol. On the two mechanically galvanised assemblies closed to a .005" gap, Mellon Institute concluded that there were no significant salt deposits on the DTIs, or bolt shanks, and the performance of these assemblies appeared to be excellent. They recommended closing DTI gaps to less than .005" on exposed similarly painted structures.

For unpainted structures:
For structures using ASTM A588 weathering type steel, tests were conducted at KTA-Tator, Inc. in Pittsburgh, PA on full-size bolted connections using TurnaSure 'weathering steel' DTIs. The bolted connections were subjected to 500 hours of cyclic exposure to an aggressive solution of de-ionized water containing 0.35% ammonium sulfate and 0.05% sodium chloride. Results demonstrated that the natural patina build-up from initial 'weathering' sealed the residual DTI gaps and protected both the connected parts as well as the structural bolts from ingress of moisture or corrosion.

Long Term Stress Relaxation.
A test was conducted in Sheffield, England starting on 7/26/63. The test specimen was measured with strain gauges immediately after tensioning, and periodically for eight years thereafter. There was no relaxation in the DTI bolted assembly over that full eight year time period.

Fatigue.
This research was conducted at the British Welding Research Institute, Cambridge, England in the 1960s. $\frac{3}{8}$" A325 bolts were assembled to minimum required bolt tensions, with DTIs under the bolt heads. The connection was subjected to fatigue loading of up to 60% of the installed bolt load. The number of fatigue cycles was 2,718,600 load reversals. There was no loosening, or drop in installed load of the bolt, nut, DTI, and washer assemblies.
Research conducted on DTIs

Prying Forces.
In 1982, at the University of Leeds in Yorkshire, England, connections with and without DTIs were subjected to prying forces. It was discovered that after the application and removal of high prying forces, the average subsequent loss of load per bolt was significantly reduced when DTIs were present. This was in contrast to when they were not present.

Transverse Vibration Loosening.
In 1998 at SPS Laboratories in Jenkintown, PA, USA, DTIs were tested in a “Junkers” transverse vibration test apparatus. This was for the new TurnaSure automotive DTI, but these results are significant for structural DTIs as well. The connection was subjected to 1000 vibration cycles per bolt test. The results showed no significant loosening when DTIs were present, and considerable fastener loosening when they were not present.

Over Tensioning.
In 1997, at the University of Idaho, in the USA, researchers sought to answer a frequently posed question. “What happens if an iron worker completely flattens a DTI during bolt installation, rather than stops close to the specified residual gap?” This addresses the fundamental questions surrounding what the term “over tensioning” actually means.

The University investigated connections fastened using completely flattened DTIs. The results showed no detrimental effects to concentric compressive or eccentric tensile properties of the high-strength bolts when “over-tensioned” just short of fracture. The researchers also noted a significant increase in the amount of “turn” beyond the yielding point of the bolt when DTIs were present, compared with when they were not used. Thus, DTIs actually provide additional protection against “over-tensioning”, which is defined as bolt breakage. (When breakage occurs above minimum tension.)

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GRAPH SHOWING RESERVE TENSILE STRENGTH OF BOLTS AFTER TIGHTENING

Bolt in tension only would fail at much higher load

A lubricated bolt when being tightened by wrench