INFLUENCE OF
'CURVED PROTRUSION' DESIGN ON INSTALLATION OF STRUCTURAL DIRECT TENSION INDICATORS (DTIs)

'Curved' Protrusion DTIs Used Under Turned Element

BACKGROUND:

The Direct Tension Indicator (DTI) originated in Great Britain, as they were invented and patented there in 1962. Originally known as Load Indicating Washers, their use was originally limited to fasteners used in structural steel. Today, DTIs are used in numerous other industries and applications in Off-Highway and Construction Equipment, Pipe Flanges and Pressure Vessels, Mill and Mining Equipment, Manufacturing Equipment, or with Anchors and Post-Tensioned Rods, etc. DTI products are covered under a number of Product Specifications, the most common of which are ASTM F959 and F959M. DTIs are also covered under a number of Installation and Use Standards, the more common of which are SAE J2486 and the RCSC Specification for Structural Joints Using ASTM A325 or A490 Bolts.
PRINCIPAL FUNCTION

The engineering function of a DTI is to provide visual and measurable evidence that the torque energy used to tighten a fastener was sufficient to generate specified tension in the fastener and corresponding clamp-force in the connection. Thus, market acceptance of the original ‘Load Indicating Washer’ was due to its ability to inform interested parties as to the state of tension in a bolted connection. Such information is of value when mechanical systems rely on fastener tension to resist static or dynamic forces, allowing proper functioning of the connection within the structural system into which it is integrated throughout its life-cycle. Use of DTIs is frequently described as an ‘Installation Method’, although it is perhaps more technically accurate to describe such washers as a method of inspection.

PRIMARY BENEFIT

The Primary Benefit to using DTIs is that they provide assurance that sufficient tension has been achieved in bolted connections regardless of how much effort (torque) was required for each fastener to be adequately tightened. Such assurance is sought by engineers familiar with the rather tenuous nature of the Torque-Tension relationship. Under laboratory conditions, the tension generated in fasteners tightened to the exact same torque may vary ±30%, and is much greater under less ideal conditions. Thus, users of DTIs are typically those who find the variability of torque-based methods unacceptable.

CURRENT STUDY

The RCSC Specification covers usage and installation of DTIs as one of four permitted methods of installation for high-strength structural bolts in structural connections. Section 8(d)(4) Installation Using Tension Indicating Devices prescribes accepted procedures for installation of DTIs. In part, this section states the following:

"Special attention shall be given to proper installation of flat hardened washers when direct-tension-indicating devices are used with bolts installed in oversized or slotted holes and when the load indicating devices are used under the turned element."
Thus, the precautionary language remained even after changes were effected that might reduce or eliminate the concerns of the original inventors. For example, Item (1) above was addressed and resolved by an amendment to ASTM F959 in 1993 which ensured that DTIs manufactured to that specification or later revisions would embody protrusions that fall within the limits of a bolt or nut bearing surface. Items (2) and (3) above changed with respect to patented design changes implemented by J&M Turner, Inc. in 1996, though study of the possible benefits was limited to SAE type DTIs.

In 1996 J&M Turner, Inc. did patent a unique protrusion design that utilized 'curved protrusions'. This design was originally developed for their SAE type Tension Indicating Washers that are used on SAE Grade 5 and Grade 8 fasteners. The curved protrusions provided significant column strength, allowing J&M Turner, Inc. to produce equally strong LIWs at much lower levels of hardness. Thereafter, the Society of Automotive Engineers issued SAE J2486, "Tension Indicating Washer Tightening Method for Fasteners". The three (3) factors outlined above having been satisfactorily resolved by the J&M Turner, Inc. design, SAE J2486 provided for use of Tension Indicating Washers without requiring the use of hardened washers under the turned element.

In 1998 J&M Turner, Inc. became TurnaSure LLC and the patents applicable to the 'curved protrusion' design thereafter belonged to TurnaSure LLC. TurnaSure itself introduced a new generation of structural DTI design in late 1998 incorporating the curved protrusions. Thus, this research investigates the impact that use of the latest curved protrusion designs may have on use of DTIs configured to be used under the 'turned element'.

TEST PROGRAM

The test program focuses on evaluating the newer TurnaSure 'curved protrusion' DTIs configured such that they are used under the 'turned element'.

All tests are performed at Laboratory Testing, Inc. in Hatfield Pennsylvania on a Skidmore-Wilhelm Bolt Tension Calibrator, Serial Number 10390, calibrated on 9/29/1999 in accordance with ASTM E4. Resolution of the instrument for reporting load is in increments of 500 lb. units, and all data is therefore reported to the nearest 1,000 lbs. The procedure followed for performance of the Tests is in accordance with ASTM F959, Appendix X1.
This study investigates the impact that the new ‘curved protrusion’ DTI design may have with respect to the recommendations presently covering use of hardened washers in TurnaSure LLC’s "Instruction Manual for Installing High-Strength Bolts with Direct Tension Indicators", 10th edition, published in July of 1999.

In the 10th and previous editions of TurnaSure’s Installation Manuals, (and those of its predecessors which go back 38 years,) instructions for installation of DTIs ‘under the turned element’ have been accompanied by a recommendation that a hardened washer be placed between the DTI and the element being turned, whether it be a bolt head or the nut. This requirement originated from the inventors of the DTI itself, having been the result of research conducted by Cooper & Turner LTD beginning in 1962.

Cooper & Turner reported that the original shape and location of the protrusions or ‘bumps’ on their Load Indicating Washers (LIWs) necessitated use of hardened washers. Their findings identified three (3) factors which led to them to require use of hardened washers:

1. The protrusions on their LIWs were located in a circle described as the ‘protrusion outer limit diameter’, which at times was larger than the bearing surface of a bolt head or nut. Thus, partial exposure of the ‘bumps’ could occur unless the ‘nut face’ washer they provided was used.

2. The protrusions on their LIWs were ‘straight-sided’, thus the turning of a bolt head or nut directly on a LIW would cut across the material, and this they reported caused wearing of the bumps and/or the bearing surface.

3. The original LIWs were comparatively hard (HRC 35+), thus the turning of a bolt head or nut directly on a LIW protrusions would potentially gall into the bearing surface of the turned element.

In the ensuing years and in each subsequent revision to Cooper & Turner Instruction Manuals, the provisions for use of hardened washers were carried over without consideration of whether or not such requirements would remain necessary as newer designs were introduced. Likewise, Instruction Manuals from J&M Turner, Inc, Bethlehem Steel Corp., etc. included similar guidelines for using hardened washers between the DTI and the ‘turned element’.
SPECIMEN PREPARATION

Four (4) distinct grouping of specimens are included within the scope of the evaluation.

(1) 1-1/8" Type 490 DTIs used under the turned element with and without hardened washers

(2) 3/4" Type 325 DTIs used under the turned element without a hardened washer

(3) New 3/4" Type 325 Weathering Steel type DTIs used under the turned element without hardened washer

(4) 3/4" Type 325 Mechanically Galvanized DTIs used under the turned element without hardened washer

TEST RESULTS

The table on the following page provides a summary of the data collected from the tests conducted on ‘curved protrusion’ DTI specimens with or without hardened washers under the turned element:

--- See Following Page ---
<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Type</th>
<th>Condition</th>
<th>Min. Required Tension</th>
<th>Level of DTI Flattening</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ NO Hardened Washer, Under Nut</td>
<td>7 X 0.005&quot; Entries @ 80 kips</td>
<td>85 kips</td>
<td></td>
</tr>
<tr>
<td>(2) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ NO Hardened Washer, Under Nut</td>
<td>7 X 0.005&quot; Entries @ 80 kips</td>
<td>90 kips</td>
<td></td>
</tr>
<tr>
<td>(3) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ YES Hardened Washer, Under Nut</td>
<td>4 X 0.005&quot; Entries @ 80 kips</td>
<td>83 kips</td>
<td></td>
</tr>
<tr>
<td>(4) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ YES Hardened Washer</td>
<td>4 X 0.005&quot; Entries @ 80 kips</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ NO Hardened Washer.</td>
<td>4 X 0.005&quot; Entries @ 80 kips</td>
<td>87 kips</td>
<td></td>
</tr>
<tr>
<td>(6) 1-1/8&quot; 490</td>
<td>‘Curved Protrusion’ NO Hardened Washer.</td>
<td>5 X 0.005&quot; Entries @ 80 kips</td>
<td>90 kips</td>
<td></td>
</tr>
</tbody>
</table>

--- See Following Page for Photographic Exhibits ---
PHOTOGRAPHS OF 1-1/8" TYPE 490
TEST #1
(DTI under nut - NO Hardened Washer)

At 80 kips (min. required tension)
0.005" feeler gauge enters ALL spaces

At 87 kips
0.005" feeler gauge enters TWO spaces
CONCLUSIONS

The Test Program found that use of 'curved protrusion' DTIs of the current design provided by TurnaSure LLC and tested in this program did not benefit from the addition of a hardened F436 washer placed under the 'turned element'. The results of tests in which the nut was tightened directly against the DTI were equal to or better than tests in which a hardened washer was used. Thus, these results demonstrate that structural DTIs with 'curved protrusions' respond in conformance with SAE's recommendations in SAEJ2486, such that no hardened washers are needed under the turned element.