



**LABORATORY
TESTING INC.**

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Certified Test Report



IMPACT OF VARIABLE LUBRICITY ON TYPE 325 STRUCTURAL DIRECT TENSION INDICATORS (DTIs)

**Evaluation of Load Measurement capabilities of
'oil-soaked', 'rusty', and 'normal' TurnaSure LLC DTIs.
(Curved Protrusion Design)**

BACKGROUND:

The origin of Direct Tension Indicators (DTIs) can be traced to Great Britain, as they were invented and patented there in 1962.¹ Originally known as Load Indicating Washers, their use was originally limited to fasteners used in slip-critical (a.k.a. friction-grip) or tension connections 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 F959² and F959M and the less explicit British Standard BS 7644. DTIs are also covered under a number of Installation and Use Standards, the most 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.

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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 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 $\pm 30\%$, and is even greater under less ideal conditions.³ Such conditions include variables common to fastener use in the 'real world', as exemplified by use of fasteners which are (1) dry or unlubricated, (2) lightly corroded or rusty, (3) 'as-is' (as received and taken from an opened package), (4) wet (e.g. installed while it is raining), or (5) nicked, etc.

CURRENT STUDY

The RCSC Specification covers usage and installation of DTIs as one of four permitted methods of installation for high-strength structural bolts.⁴ Section 8(a) Installation and Tightening of the RCSC Specification prescribes Handling and Storage requirements for fasteners, including protecting them from dirt or moisture, cleaning and relubrication, return of unused fasteners to 'protective storage' at the end of each shift, etc. There is some doubt as to whether such provisions can be or are completely followed on all construction projects. Thus, it is useful to consider what impact, if any, results from conditions commonly associated with construction sites.

This study investigates the effects of two conditions, (1) rust, and (2) oil, on the ability of the new 'curved protrusion' DTI design⁵ to accurately measure tension in high-strength structural bolts. Thus, predictions about tension in bolted connections with DTIs under circumstances where ideal Storage and Handling requirements were either not followed or were impossible to follow can be made.

In a similar study⁶ performed by SPS Technologies in 1993, it was reported that DTIs of the original British design were indeed affected by their level of lubricity. That research found variability on the order of 18% between the 'dry' and 'oiled' original design DTIs of Cooper & Turner. Thus, 'oiled' DTIs flattened at lower loads, and 'rusty' DTIs flattened at higher loads. This contrasted with the results of the DTIs of J&M Turner, Inc., which demonstrated statistically insignificant variability between the oiled and dry conditions. (J&M Turner, Inc. had been granted a patent in 1992 for their new DTI design.)

Through a 1998 merger, the J&M Turner, Inc. patents have since become the property of TurnaSure LLC. TurnaSure itself introduced a new generation of DTI design in late 1998. Thus, this research is to be conducted in order to quantify the impact that field factors such as oil or rust may have on the efficacy of the most current DTI designs used on structural bolts.

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TEST PROGRAM

The test program will focus on measuring the compressive force under which DTIs taken from the same product lots and subject to different treatments perform. Three (3) categories of DTIs will be evaluated: (1) DTIs 'as-received' with their normal out-of-the-box finish, (2) DTIs submerged and soaked in an oil bath for an extended period, and (3) DTIs left outdoors to weather for an extended period. To maximize surface condition variability, and avoid unnecessary complexity related to effectiveness of coatings, plain finish DTIs are used for all tests.

All tests are performed on a Digital Compression-Load Analyzer, calibrated in accordance with ASTM E4. Resolution of the instrument for reporting load is in increments of 100 lb. units, and all data is therefore reported to the nearest 100 lbs. The procedure followed for performance of the Compression-Load Tests is in accordance with ASTM F959, Annex A1. Compression-Load Tests are sequenced (alternated) between treatments to ensure data trends would be detected, and could not implicate alternate hypotheses.

SPECIMEN PREPARATION

Three (3) distinct grouping of specimens are included within the scope of the evaluation. All specimens were originally part of the same production lot, #343H24. In keeping with ASTM F959 requirements, each individual piece is marked for traceability to that lot. The Production Lot method required by ASTM assures that all specimens from the subject lot are derived from a discreet population of up to 25,000 pieces, are produced from the same original mill heat of raw material, and are processed essentially together through all manufacturing operations and treatments.

A random sample of 150 pieces were provided for use in the study. The specimens were then broken down into three (3) equal subgroups. Each subgroup was then subject to its unique treatment. The first group of DTIs remained in their shipping container until just before their imminent use in the test program. This first group is thus considered the 'normal' or 'as-received' condition, in keeping with language in the RCSC Specification. Figure 1. is a photograph depicting the specimens from this group.

The second group of specimens were placed on a concrete pad behind the laboratory and exposed to the outdoor environment of Dublin, Pennsylvania from August 24th to September 28th, 1999. Rainfall during the period was ~10", much of which fell during the middle of September as hurricane Floyd passed through the area. Temperatures ranged from lows in the 60's to highs in the 90's (°F) during the exposure period. Figure 2 is a photograph depicting the specimens from this group.

The third group of specimens were submerged in an oil bath, consisting of Mobil Vactra Oil #2. These specimens remain in the bath until just prior to testing. No attempt is made to wipe them clean or remove excess oil. Figure 3 is a photograph depicting the specimens from this group.

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TEST RESULTS

The following table provides a statistically summary of the data collected from the tests conducted on 'curved protrusion' DTI specimens from each of the three (3) different surface conditions:

	'Normal', 'As-Received'	'Rusty'	'Oiled'
Average (mean)	31,490 lbs.	31,090 lbs.	31,240 lbs.
Standard Deviation	400 lbs.	580 lbs.	435 lbs.
Std. Dev. %	1.27 %	1.87 %	1.39 %
Low Value	30,500 lbs.	30,000 lbs.	30,000 lbs.
High Value	32,800 lbs.	32,200 lbs.	32,200 lbs.
Average (median)	31,500 lbs.	31,200 lbs.	31,200 lbs.

CONCLUSIONS

The Test Program found no statistically significant difference between the load measuring capabilities of brand new (as-received), oiled, or rusty 'curved protrusion' Direct Tension Indicators. Regardless of surface condition, each group demonstrated very comparable Compression-Load measurement capability. Variability within each group was also very comparable.

The research suggests that use of 'curved protrusion' DTIs under field bolting conditions which may include corrosion, rust, oil, or lubricant will continue to yield accurate indication that specified bolt tension has been achieved in structural bolts, and corresponding clamp load generated in bolted connections.

¹ Patent Number 5,015,132, Originally held by Cooper & Turner, Sheffield, England.

² Current Revision: ASTM F959-99, Standard Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners.

³ Torque Control of Assembly, Chapter 29, Handbook of Bolts & Bolted Joints, John H. Bickford and Sayed Nassar.

⁴ Specification for Structural Joints Using ASTM A325 or A490 Bolts, Load & Resistance Factor Design, 1994, Approved by the Research Council on Structural Connections.

⁵ A uniquely shaped DTI recently introduced. U.S. Patent #5,667,346 Property of TurnaSure LLC



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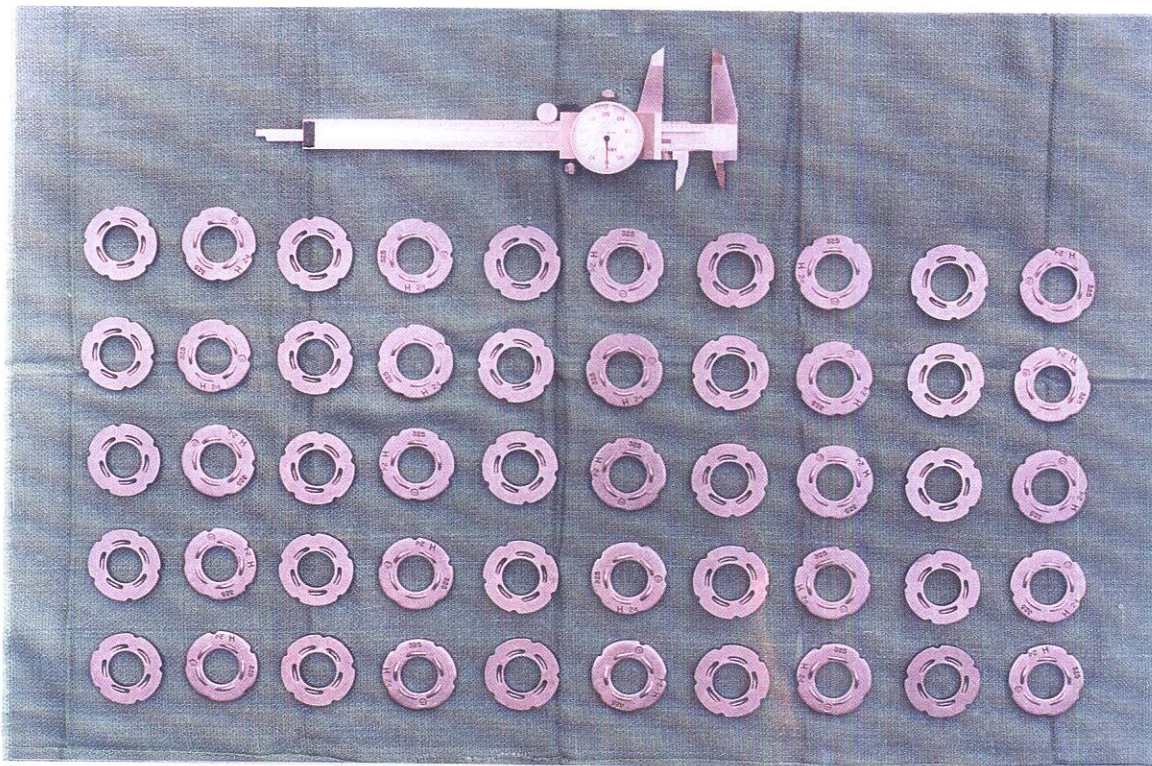


FIGURE 1

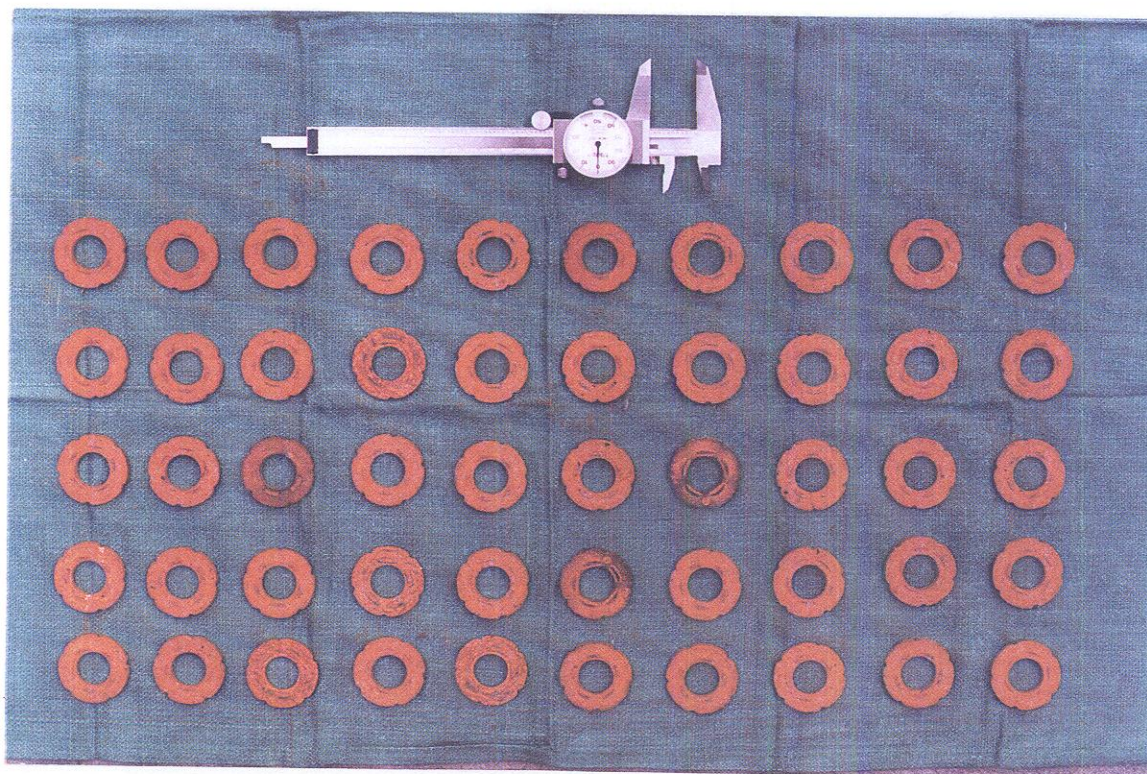


FIGURE 2

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FIGURE 3