Effect of Washer Placement on Performance of Direct Tension Indicators

A Study Prepared for TurnaSure, LLC

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July 23, 2009

By

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I. Purpose and Scope

The purpose of this study is to evaluate the performance of direct tension indicators for various configurations under controlled laboratory conditions. Tests are performed for ASTM A325 3/4"and 7/8" bolts and ASTM A490 1" bolts with standard ASTM F959 direct tension indicators with and without ASTM F436 standard hardened washers. For the A325 3/4" and 7/8" bolts, both galvanized and plain finish TurnAnut DTIs are also evaluated. All DTIs of the same size were from the same production lot. These conditions are summarized in Table 1.

Table 1. Matrix of configurations considered in testing

	Diameter	Type	Surface Finish	Hardened Washer?	Number of Tests
TurnaSure DTI					
	3/4"	325	Plain	Yes	30
	3/4"	325	Plain	No	30
	7/8"	325	Plain	Yes	30
	7/8"	325	Plain	No	30
	1"	490	Plain	Yes	30
	1"	490	Plain	No	30
TurnAnut DTI					
	3/4"	325	Plain	No	30
	3/4"	325	Galvanized	No	30
	7/8"	325	Plain	No	30
	7/8"	325	Galvanized	No	30

II. Code requirements for Direct Tension Indicators

Direct tension indicators must meet the requirements of ASTM Standard F959. Section 7 of the *Specification for Structural Joints Using ASTM A325 or A490 Bolts* describes the requirements to verify that fastener assemblies and procedures result in the required post tightening performance. The specification calls for the use of a tension calibrator to confirm the performance of the fastener assembly and the pretensioning method to be used by the bolting crew. Section 8 describes installation of fastener components. Section 8.2.4 specifically describes Direct-Tension-Indicator Pretensioning.

The specification calls for a representative sample of fastener assemblies to be tested for each combination of diameter, length, grade and lot to be used. The purpose of the testing is to ascertain that the fastener assembly and fastening procedure develops a pretension equal to or greater than 1.05 times the values specified in Table 8.1 of the specification. The values from

Table 8.1 of interest to this test program, as well as the values scaled by 1.05 used for initial pretensioning in this study are reported in Table 2.

Table 2. Significant Tensile Forces for Pretensioned and Slip Critical Bolts

Nominal Bolt Diameter d_b (in)	Specified Minimum Bolt Pretension T_m (kips)		1.05 times Specified Minimum Bolt Pretension (kips)		Minimum Tensile Capacity (kips)	
	ASTM A325 Bolts	ASTM A490 Bolts	ASTM A325 Bolts	ASTM A490 Bolts	ASTM A325 Bolts	ASTM A490 Bolts
3/4	28		29		40	
7/8	39		41		56	
1		64		67		91

III. Experimental Program

The experimental program consisted of tension tests of TurnaSure DTIs (Type 325 3/4", 7/8", and Type 490 1") and TurnaSure TurnAnut DTIs (Type 325 3/4" and 7/8"). The devices tested are shown in Figure 1. The tests of DTIs were performed with four configurations including plain finish DTIs bearing directly against the face of the nut, plain finish DTIs bearing against a hardened washer, and plain and mechanically galvanized TurnAnut DTIs as shown in Figures 1 and 2. All DTIs of the same size were from the same production lot. The TurnAnut DTI consists of a nut to which a DTI has been attached by staking. A summary of the program was provided in Table 1.

a) TurnaSure DTI b) TurnaSure TurnAnut DTI

Figure 1. Views of TurnaSure DTI and TurnAnut DTI. The images show the devices before and after testing.

Figure 2. Test configurations from left to right; DTI without washer, DTI with washer, plain TurnAnut DTI, galvanized TurnAnut DTI.

Bolts were tensioned with a Skidmore-Wilhelm bolt tension calibrator with a digital readout. The device was calibrated on April 29, 2009 (see attached calibration certificates in Appendix A) and all testing was performed between May11 and May 26, 2009. For loading, the bolts were placed through the back of the calibrator and the nut was the turned element. The bolts were initially tensioned to 1.05 times the load specified in Table 8.1 of *Specification for Structural Joints Using ASTM A325 or A490 Bolts*. The number of gaps open more than 0.005" was recorded using a feeler gage. The bolt tensions were then incrementally increased and the number of open gaps measured at each load stop until only one gap remained open. In some instances the final load increment resulted in all gaps closing. The tension load required to close all or all but one gap was recorded. After loading it was verified that the nut could be rethreaded for the length of the bolt. The loading plates of the tension calibrator required refacing at regular intervals. No more than 20 test repetitions were performed on a plate without refacing. The test equipment is shown in Figure 3.

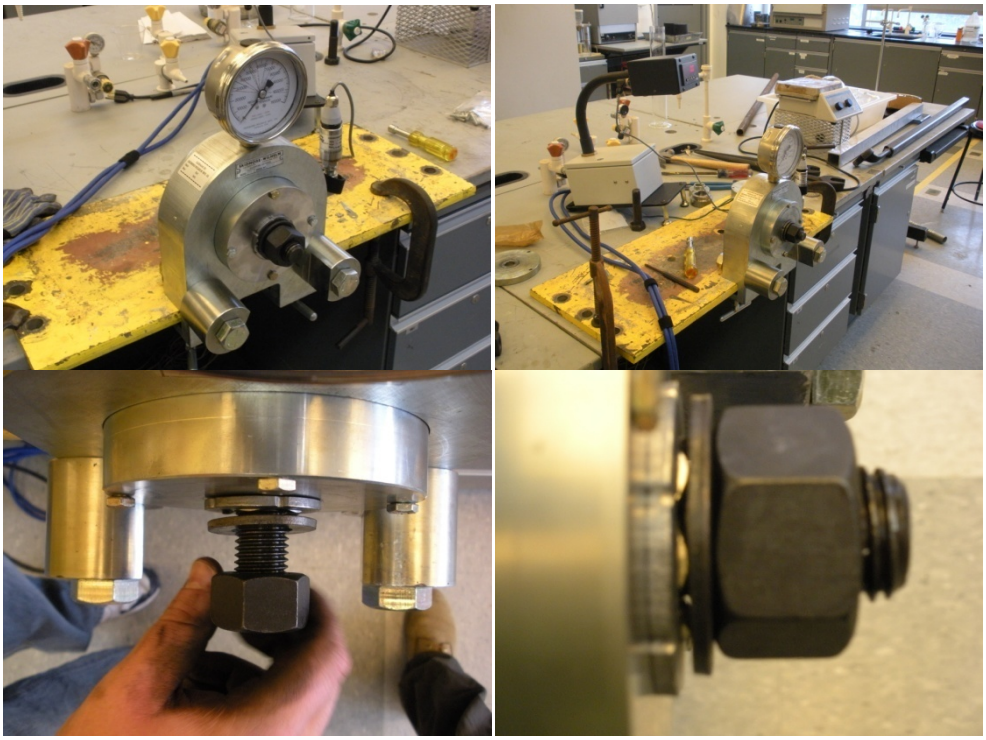

Figure 3. Test setup.

IV. Results

There are two key types of results reported in this study. The first result reported is the number of gaps open when the pretension in the bolt reaches 1.05 times that specified in Table 8.1 of the *Specification for Structural Joints Using ASTM A325 or A490 Bolts*. These required pretension values are reported in Table 2. These data are used to verify that the required pretension is reached prior to more than half of the DTI gaps closing. The second result reported is the load required to close all or all but one of the DTI gaps to verify that this condition does not overstress the bolt.

The average numbers of gaps open at 1.05 times the minimum pretension load and the standard deviation of these results are provided in Table 3. Figures 4 through 6 are pie charts representing the number of gaps resulting from tests on 3/4", 7/8" and 1" bolts, respectively. The preload values were 29 kips for 3/4" A325 bolts, 41 kips for 7/8" A325 bolts, and 67 kips for 1" A490 bolts.

Table 3. Average numbers of gaps open at 1.05 times minimum pretension load.

Condition (Preload)	Ave. Number of Gaps Open	Standard Deviation
3/4" A325 (29 kips)	(5 possible)	
w/o washer	4.10	0.82
w/washer	3.57	0.73
plain TurnAnut DTI	4.87	0.43
galvanized TurnAnut DTI	5.00	0.00
7/8" A325 (41 kips)	(5 possible)	
w/o washer	3.72	0.80
w/washer	3.49	0.85
plain TurnAnut DTI	4.93	0.37
galvanized TurnAnut DTI	4.27	0.74
1" A490 (67 kips)	(7 possible)	
w/o washer	6.60	0.89
w/washer	5.33	1.35

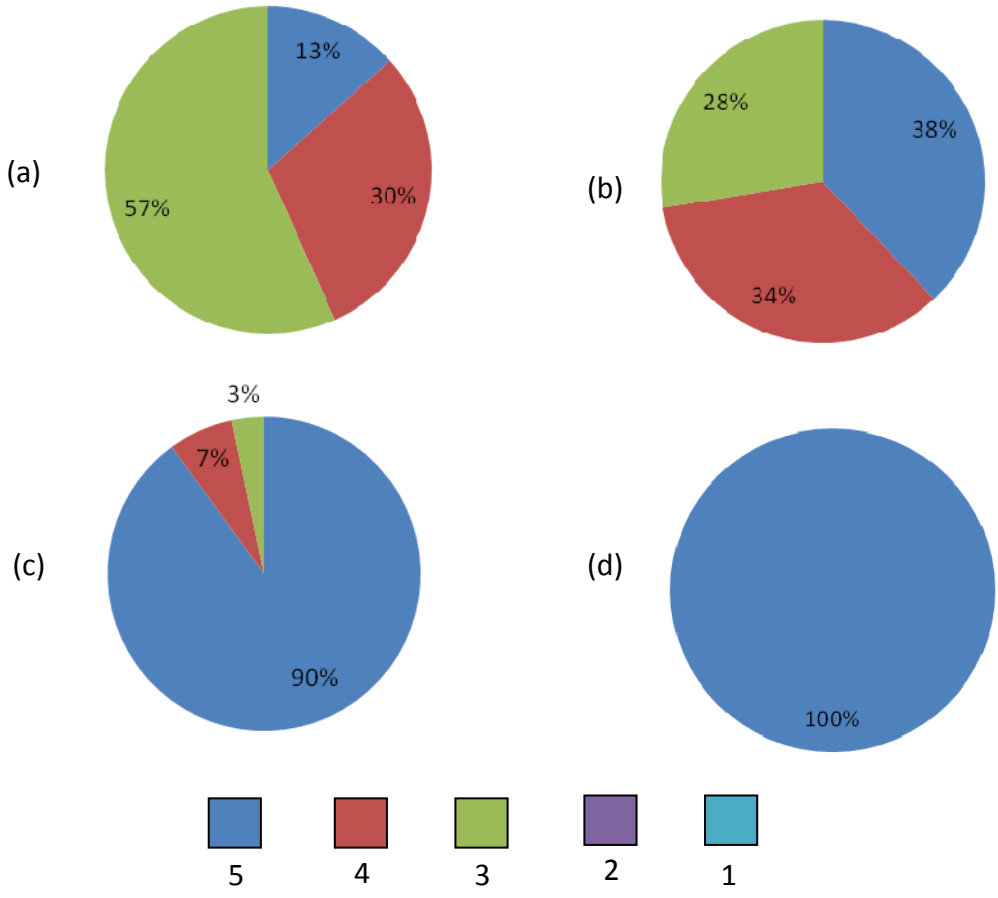

Figure 4. Number of gaps open at preload (29 kips) for 3/4" A325 bolts with (a) hardened washer, (b) without hardened washer, (c) plain TurnAnut DTI, (d) galvanized TurnAnut DTI.

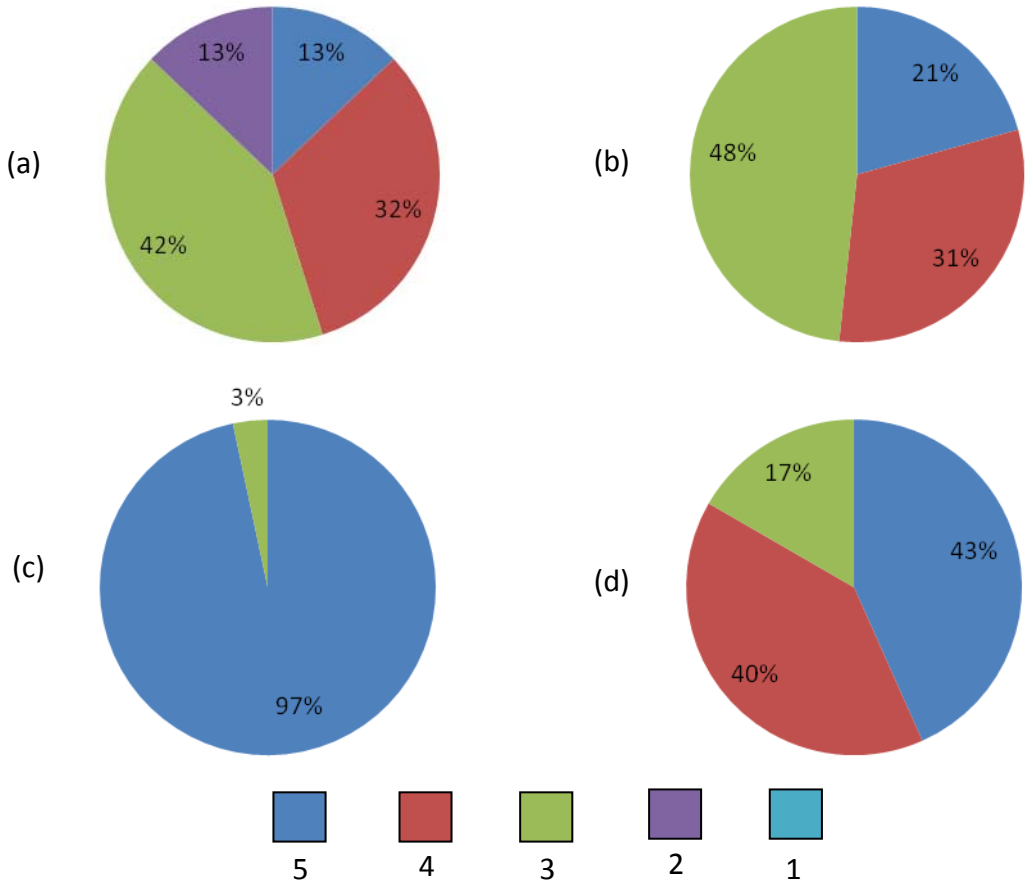

Figure 5. Number of gaps open at preload (41 kips) for 7/8" A325 bolts with (a) hardened washer, (b) without hardened washer, (c) plain TurnAnut DTI, (d) galvanized TurnAnut DTI.

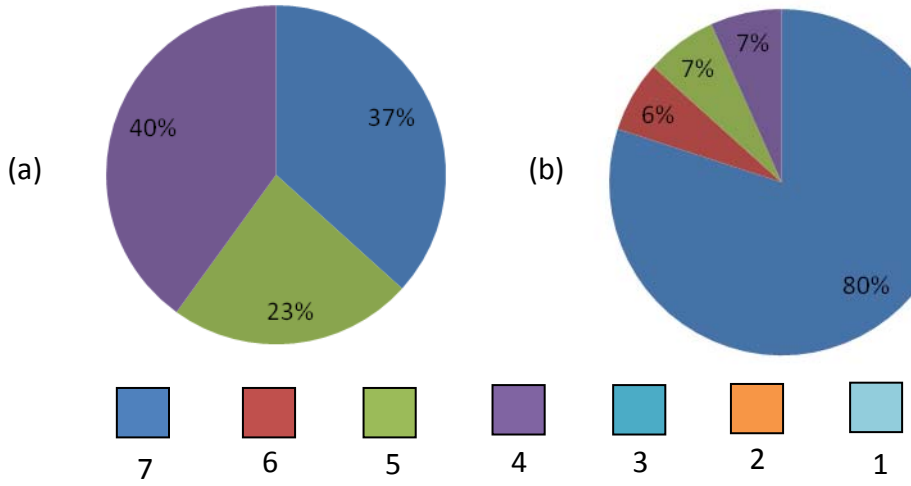

Figure 6. Number of gaps open at preload (67 kips) for 1" A490 bolts with (a) hardened washer, (b) without hardened washer.

All tests resulted in at least half of the gaps remaining open at the specified preload (ASTM value times 1.05) with the exception that four tests of 7/8" plain A325 bolts with F436 washers resulted in 2 of 5 gaps open at the specified preload. Use of a DTI alone compared to use of a DTI with a hardened washer against the face of the nut resulted in a higher average number of gaps open at the preload for the DTI alone for all size bolts tested. The TurnAnut DTI, whether plain or galvanized, tended to have the most gaps open at preload and the smallest spread in the results.

The average loads required to close all but one or all of the DTI gaps are reported in Table 4. Cumulative density functions of the peak load data are plotted in Figures 7 through 9. On average, the peak loads recorded are 82% to 96% of the tensile capacity of the bolts. Four of 30 tests of galvanized 3/4" bolts exceeded the minimum specified tensile capacity of the bolt. No other tests exceeded the minimum. Use of a hardened washer against the face of the nut tended to result in a slightly greater spread in the peak load data compared with a DTI directly against the nut face. All nuts could be rethreaded for the length of the bolt after testing.

Table 4. Average loads required to close all but one or all of the DTI gaps.

Condition (Minimum Tensile Capacity)	**Ave. Peak Load (kips)**	**Standard Deviation (kips)**	**Percent of Capacity**
3/4" A325 (40 kips)			
w/o washer	35.1	1.03	88
w/washer	35.9	1.74	90
plain TurnAnut DTI	35.3	1.50	88
galvanized TurnAnut DTI	38.2	1.60	96
7/8" A325 (56 kips)			
w/o washer	45.8	1.42	82
w/washer	47.4	2.46	85
plain TurnAnut DTI	48.2	0.89	86
galvanized TurnAnut DTI	47.2	1.65	84
1" A490 (91 kips)			
w/o washer	80.0	3.47	88
w/washer	77.4	3.92	85

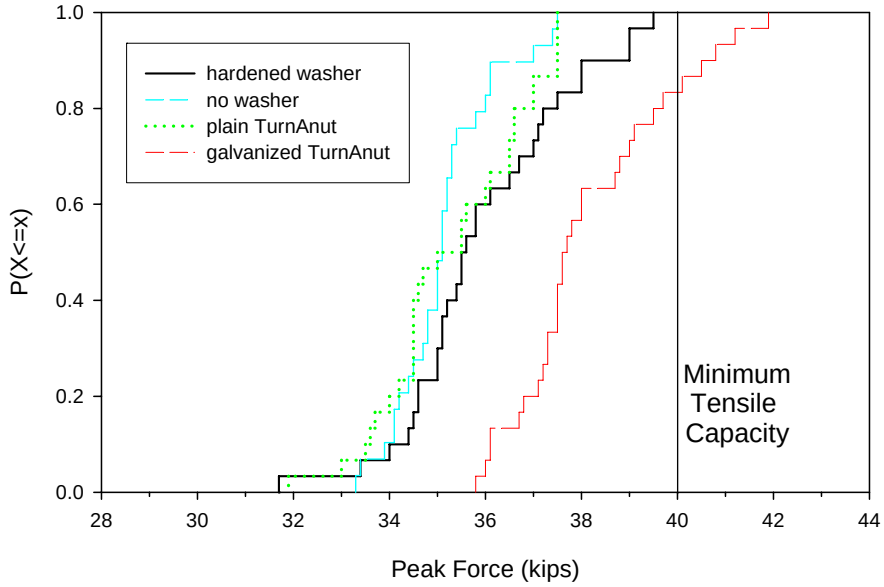

Figure 7. Cumulative density function of loads required to close all but one or all gaps, 3/4" A325 bolts (minimum tensile strength is 40 kips).

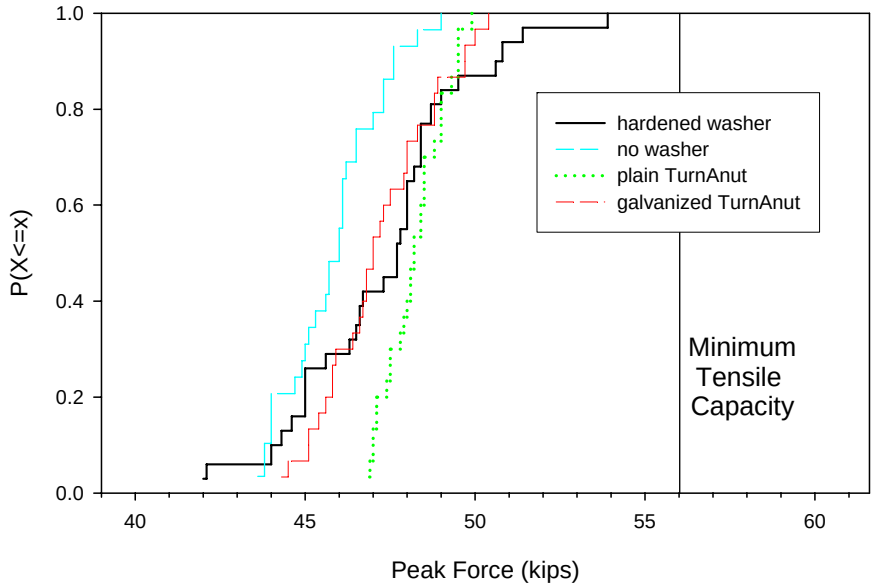

Figure 8. Cumulative density function of loads required to close all but one or all gaps, 7/8" A325 bolts (minimum tensile strength is 56 kips).

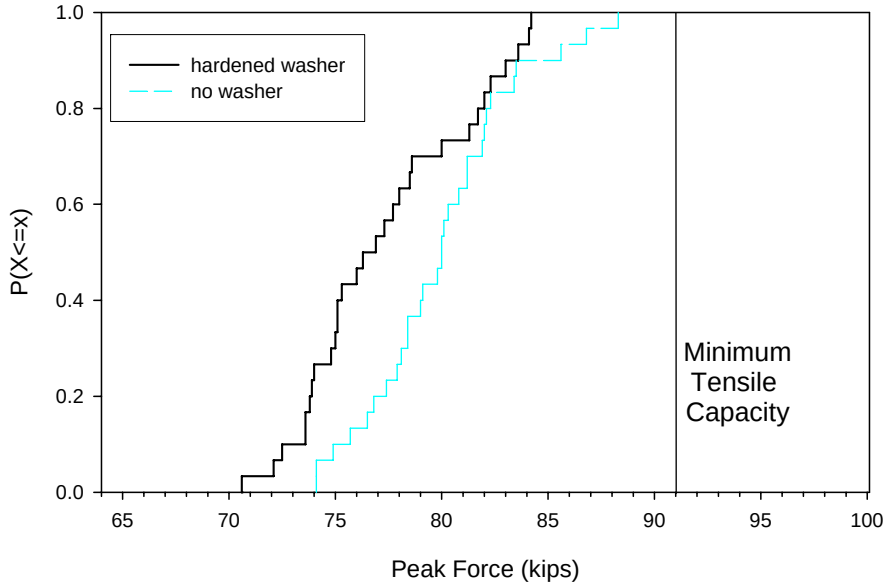

Figure 9. Cumulative density function of loads required to close all but one or all gaps, 1” A490 bolts (minimum tensile strength is 91 kips).

V. Analysis and Discussion

One-way Anova t-test analysis was performed to determine if there were statistically significant differences in the average loads required to close all but one or all of the gaps of the DTI to refusal of the 0.005” feeler gage. Results of this analysis were:

- The differences in the measured average peak loads were not statistically significant when comparing the “with-washer” configuration to the TurnAnut DTI configuration for plain A325 3/4” or 7/8” diameter bolts.
- The differences in the measured average peak loads were statistically significant when comparing the “with-washer” configuration to the TurnAnut DTI configuration for galvanized A325 3/4” bolts. However, the difference was not statistically significant when comparing the “with-washer” configuration to galvanized A325 7/8” TurnAnut DTIs. The “with-washer” configuration with 3/4" diameter bolts resulted in lower peak bolt tension required to close one or all gaps than was required with the galvanized TurnAnut DTI.
- The differences in the measured average peak loads were statistically significant when comparing the “with-washer” condition to the “without-washer” configuration for all sizes tested. However, the differences were not in the same direction for all sizes. For A325 3/4" or 7/8” diameter bolts the force required to close one or all of the gaps to less than 0.005” was higher for the hardened washer configuration. The trend was reversed in the 1” diameter A490 bolts.

While the analysis performed indicates there are statistically significant differences in some of the measured results, there was not a consistent trend in these differences. In addition, these statistical findings must be considered in light of the test program itself. The peak loads recorded were those required to close all but one or all of the gaps between the DTI and washer or bolt. This was because in some instances the load increment applied to the bolt resulted in enough gaps closing to bypass the one-gap-closed condition. In addition, the load increments typically ranged from 0.4 kips to 1.5 kips. Therefore, the load increments are equal to or of the same magnitude as the measured differences in peak load values. Given these considerations, these results should not be extended beyond stating that the comparable behavior was achieved with all of the bolt/DTI/washer/nut configurations considered.

VI. Summary and Conclusions

Tests of direct tension indicators were performed to evaluate the effect of nut and washer configuration on pretension achieved. Test configurations included plain DTIs against the face of the nut, DTI's and hardened washer against the face of the nut, and plain and mechanically galvanized TurnaSure TurnAnut DTIs. For all tests, the nut was the turned element and thirty repetitions were performed for all series.

The findings were

- All tests resulted in the minimum required pretension (ASTM minimum pretension + 5%) being reached prior to more than half of the DTI gaps closing to less than 0.005".
- Use of a DTI alone compared to use of a DTI with a hardened washer against the face of the nut resulted in a higher average number of gaps open at the preload for the DTI alone for all size bolts tested, even when such DTIs were from the same production lot.
- The TurnAnut DTI, whether plain or galvanized, tended to have the most gaps open at preload and the smallest spread in the results.
- The average tensile loads required to close all but one or all of the DTI gaps to less than 0.005" were 82% to 96% of the minimum tensile capacity of the bolts.
- Use of a hardened washer against the face of the nut tended to result in a slightly greater spread in the peak load data compared with a DTI directly against the nut face.
- In some cases statistically significant differences were measured for the average tensile loads required to close all but one or all of the gaps to less than 0.005". However, the trends were not consistently in the same direction and the differences in the means were less than or comparable to the load increments being applied during the testing.

Based on the results of this test program it is concluded that the use of direct tension indicators with or without hardened washers against the turned element for ASTM A325 3/4" and 7/8"

diameter bolts and ASTM A490 1” diameter bolts results in comparable performance in providing the required bolt pretension. In addition, the presence or absence of the hardened washer made no difference in the performance of the direct tension indicators at the load levels required to close all but one or all of the gaps. The staking of a direct tension indicator to a nut to produce the TurnAnut DTI configuration with either plain or galvanized surfaces also resulted in behavior comparable to a DTI with and without a hardened washer against the turned element.

VII. References

Research Council on Structural Connections (2004). *Specification for Structural Joints Using ASTM A325 or A490 Bolts*, c/o American Institute of Steel Construction, Inc., Chicago, IL.

American Society for Testing and Materials (1999). *ASTM F959-99a Standard Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners*.

American Society for Testing and Materials (1997). *ASTM A325-97 Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*.

American Society for Testing and Materials (1997). *ASTM A490-97 Standard Specification for Heat Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength*.

American Society for Testing and Materials (1991). *ASTM B695-91 Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel*.

American Society for Testing and Materials (1993). *ASTM F436-93 Standard Specification for Hardened Steel Washers*.

Appendix A – Calibration Certificates

SKIDMOREWILHELM

442 South Green Rd
South Euclid, OH 44121
216-481-4774
216-481-2427 fax
www.skidmore-wilhelm.com

Calibration Report

Reading	Actual Load	% Deviation
20,000	20,023	0.12%
40,000	39,971	-0.07%
60,000	59,977	-0.04%
80,000	80,039	0.05%

Date of Calibration	4/29/2009
Model/Serial Number	M15729
Technician	William Robinson
Temperature (°F):	69

Tested with Morehouse Proving Ring S/N 2417, traceable to NIST per Report No. 2417F0606, dtd. 6/06/06.

SKIDMORE-WILHELM
Manufacturing Company
422 South Green Rd
South Euclid, OH 44121
216-481-4774
216-481-2427 fax
www.skidmore-wilhelm.com

CERTIFICATE OF CALIBRATION

DIGITAL METER

Calibration Date: 39931

Model/Serial Number: M15729

Lab Temperature: 69° F.

Technician: William Robinson

Applied Load KIPS	Meter Reading KIPS Trial One	Meter Reading KIPS Trial Two
10.0	9.9	10.0
20.0	19.9	19.9
40.0	39.9	40.0
60.0	59.9	59.9
80.0	79.9	80.0

Tested with Morehouse Proving Ring S/N 2417, traceable to NIST per Report No. 2417F0606, dtd. 6/06/06.