Time-Dependent Behavior of Structural Bolt Assemblies with TurnaSure Direct Tension Indicators and Assemblies with Only Washers

A Report Prepared for TurnaSure, LLC

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Problem Statement: Direct Tension Indicators (DTIs) are one-way mechanical load cells used in the pretensioning of mechanical fasteners. DTIs have been used in structural and other applications since their inception in England in 1962. Direct Tension Indicators have been produced to numerous worldwide product standards, including BS 7644 Part 1, ASTM F959, ASTM F959M, ASTM F2437, and EN-14399-9.

In this report the creep/relaxation load losses of structural bolt assemblies that include the current TurnaSure, LLC DTIs are compared to load losses of structural bolt assemblies that do not include any DTI's. In all cases, the assemblies are evaluated using criteria derived from the 13th edition of the *Manual of Steel Construction*, published by the American Institute of Steel Construction (AISC, 2005) and AASHTO bridge requirements (U.S. Department of Transportation (1991)).

Scope: In this study, time-dependent loss of initial pretension in 7/8 inch ASTM A325 and A490 bolted assemblies were investigated. The tests compared the behavior of assemblies with Type 325 TurnaSure DTIs attached to a nut to assemblies with washers only and compared assemblies with Type 490 DTIs to assemblies with washers only. Loads in the bolted assemblies were monitored for 1000 hours (42 days) using an ultrasonic technique meeting the recommendations of *ASTM E1685 – Standard Practice for Measuring the Change in Length of Fasteners Using the Ultrasonic Pulse-Echo Technique* . The results presented in this report are a subset of results from a larger study that also included DTIs that are no longer manufactured, galvanized assemblies, assemblies using a competitor's DTI, and assemblies with oversized holes.

Experimental Program:

Test Matrix

The bolted assembly configurations that are considered in this report are described in Figure 1. In this figure, the curved arrow denoted the element that was turned during tensioning. All bolts were 7/8 inch nominal diameter with coarse (UNC) threads. All bolt assemblies were installed through a 1.5 inch thick plate, and used 3 inch long bolts. The grip length corresponds to an effective length of approximately 2.15 inch, which meets the recommendation of a ratio of effective length to bolt diameter of at least 2:1 found in *ASTM E1685 – Standard Practice for Measuring the Change in Length of Fasteners Using the Ultrasonic Pulse-Echo Technique*. The test matrix described in this report is summarized in Table 1. The tensioning methods used were intended to produce a range of pretension loads, as would be expected in field installations.

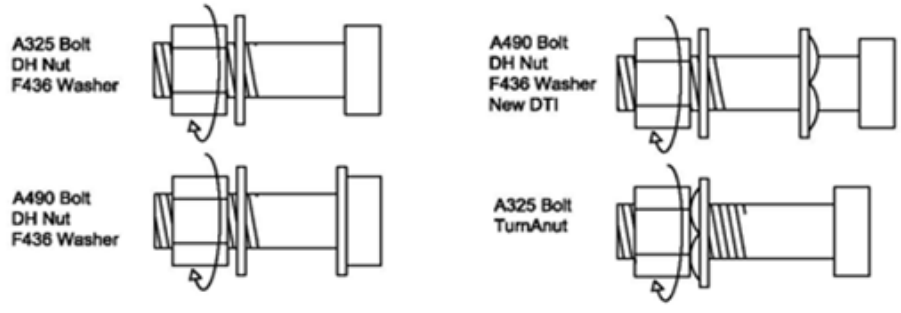


Figure 1. Bolt assembly configurations used in the test procedure.

Table 1. Test Matrix

Bolt Hole diam. (inches)	Test Plate Grade	Structural Bolt Grade (ASTM)	Washer Spec. (ASTM)	Heavy Hex Nut Grade (ASTM A563)	Num. of Samples	DTI Type and Grade (ASTM F959)
15/16	ASTM A36	A325	-	Plain DH	5	Type 325
15/16	ASTM A36	A490	F436	Plain DH	5	Type 490
15/16	ASTM A36	A325	F436	Plain DH	5	None
15/16	ASTM A36	A490	F436	Plain DH	5	None

Pre-installation verification of the Assemblies

A pre-installation verification procedure was employed for each combination of the structural bolt assemblies used. All bolts, nuts, washers, etc. for the pre-installation testing were in the as-received condition. The purpose of the pre-installation verification was to verify the suitability of the assemblies for pretensioning and to confirm the procedure to be used during tightening during the creep/relaxation tests.

For the TurnaSure products, three samples of each assembly were randomly selected. Each bolt assembly was tensioned with a hand wrench with a handle extension on a bolt tension calibrator to the required minimum bolt pretension indicated in Table 7.1 of *Specification for Structural Joints Using High-Strength Bolts* (41 kips for A325 and 51 kips for A490) and the number of gaps open to a 0.005 inch feeler gage was recorded. Then each was tensioned incrementally until there was refusal of a 0.005 inch feeler gage in at least half of the gaps. The 0.005 inch feeler gage rather than 0.015 inch was selected as compatible with AASHTO bridge requirements (U.S. Department of Transportation (1991)) and because it should result in somewhat higher loads on the bolt assemblies. Results of pre-installation verification are provided in Table 2.

Table 2. Results of pre-installation verification for bolt assemblies using TurnaSure DTIs.

Assembly Type	**Assembly Number**	**Minimum Pretension Load (kips)**	**Gaps Open at Min. Pretension**	**Load at 50% Refusal (kips)**	**Gaps Open at 50% Refusal**
Type 325 TurnaSure DTI attached to nut	1	41	5 of 5	46	2 of 5
	2	41	5 of 5	47	2 of 5
	3	41	5 of 5	47	2 of 5
Type 490 TurnaSure DTI	1	51	6 of 6	56	3 of 6
	2	51	6 of 6	56	3 of 6
	3	51	6 of 6	57	3 of 6

For the A325 and A490 assemblies without DTIs, increasing torque was applied with a 1000 ft-lb torque wrench until a tension of 41 kips and 51 kips respectively was obtained at which point the torque was

recorded. The bolt tension was measured on a bolt tension calibrator. The resulting torque measurements are shown in Table 3.

Table 3. Results of pre-installation verification for assemblies without DTI.

Assembly Type	Assembly Number	Load (kips)	Torque (ft-lbs)
A325 Assembly (no DTI)	1	41	665
	2	41	530
	3	41	710
	average	41	635
A490 Assembly (no DTI)	1	51	700
	2	51	750
	3	51	800
	average	51	750

Timing of Measurements

Initial tensioning of the bolt assemblies was performed on August 1st, 2011. Initial tension was measured using an ultrasonic method at approximately 20 minutes into the test, and within 25 minutes after tensioning. The measurements were taken at approximately 20 minutes to simulate field practices in which all bolts on an assembly are snug tightened and then fully tightened followed by verification of required tension with the feeler gage. Ultrasonic measurements were performed by Load Control Technologies in King of Prussia, PA and observed by the authors. Additional measurements were made over a period of 42 days.

Results

Initial Tension in the Bolt Assemblies

The bolted assemblies were tensioned in a manner intended to reproduce the scatter in initial tension that could be expected in field applications. Adequate tensioning of the bolted assemblies employing DTIs were determined based on measurement of the gaps in the DTIs. All bolted assemblies were first tightened to snug-tight with a hand wrench, and then further tensioned using an impact wrench. Tension was increased until at least half of the DTI gaps refused a 0.005 inch feeler gage. The number of gaps closed when tensioning was stopped is provided in Table 4 for each assembly. In some cases, multiple gaps closed nearly simultaneously, resulting in more than half of the gaps being closed at the end of tensioning.

The results from the pre-installation verification were used to establish the initial tension of the assemblies that did not have DTIs. The A325 and A490 assemblies without DTIs were first tightened to snug with a hand wrench and then further tensioned with a 1000 ft-lb torque wrench to the average torque measured in the pre-installation verification (635 ft-lb for A325 and 750 ft-lb for A490, as per Table 3). The resulting bolt tension measured 20 minutes after initial tensioning for each assembly is shown in Figure 2.

All assemblies employing DTIs reached the minimum pretension of 39 kips for A325 assemblies or 49 kips for A490 assemblies, as specified in RCSC *Specification* (2009) Table 8.1. Because the average torques measured at the specified tensile load during the pre-installation verification were used for tensioning the assemblies with washers only, approximately half reached the minimum initial pretension for these tests. The spread in the initial tension for the A325 assemblies were similar with the highest spread occurring with the assemblies without DTIs. The spread in initial tension ranged from 10.6 kips for the Type 325 and 13.0 kips for the washer-only assemblies. For the A490 groups, the initial tensioning load for DTI assemblies had a spread of 7.2 kips and the initial tensioning loads for washer-only assemblies had a spread of 13.8 kips.

Table 4. Results of feeler gage testing following tensioning.

Assembly Type	Assembly Number	Gaps Closed
Type 325 TurnaSure DTI attached to nut	1	3 of 5
	2	3 of 5
	3	3 of 5
	4	3 of 5
	5	3 of 5
Type 490 TurnaSure DTI	1	3 of 6
	2	3 of 6
	3	4 of 6
	4	3 of 6
	5	4 of 6

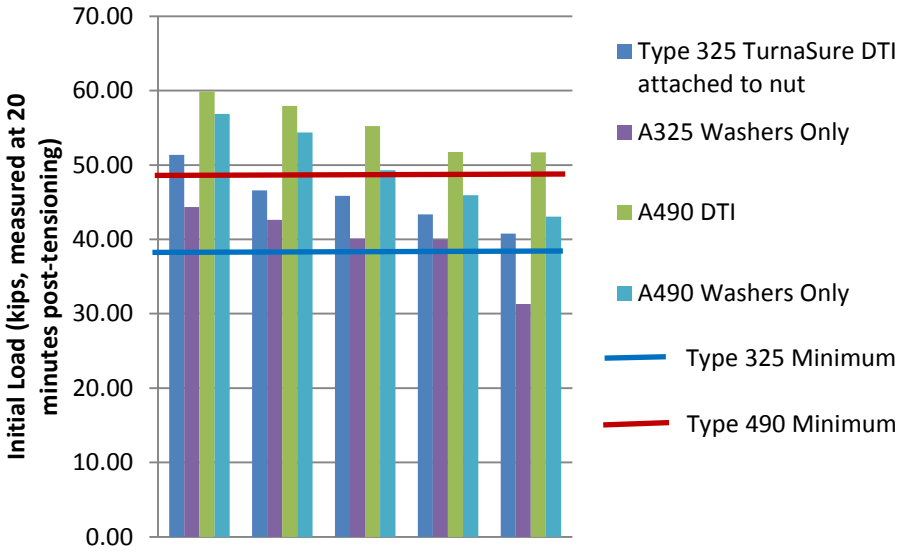


Figure 2. Tension (measured at 20 minutes) in the bolts tightened to replicate field installation methods and techniques (feeler gage for DTIs and measured torque for washers only).

Time-dependent loss of pretension

The time history of measured bolt tension is plotted in Figure 3 for assemblies with washers and Figure 4 for assemblies with DTIs. The majority of the losses occur in the first 24 hours after loading and the bolts are essentially stable after 7 days. Very little change occurs beyond the first week and there are both positive and negative fluctuations in the measured loads beyond that point. It appears that future studies could be terminated at 7 days (168 hours) to improve the efficiency of data collection.

Despite any time-dependent losses and the varied initial loads observed in the assemblies with DTIs that were tensioned using field methods, all maintained a tension greater than the RCSC specified minimum through 1000 hours of testing within the range of load fluctuation observed beyond the seven day measurements.

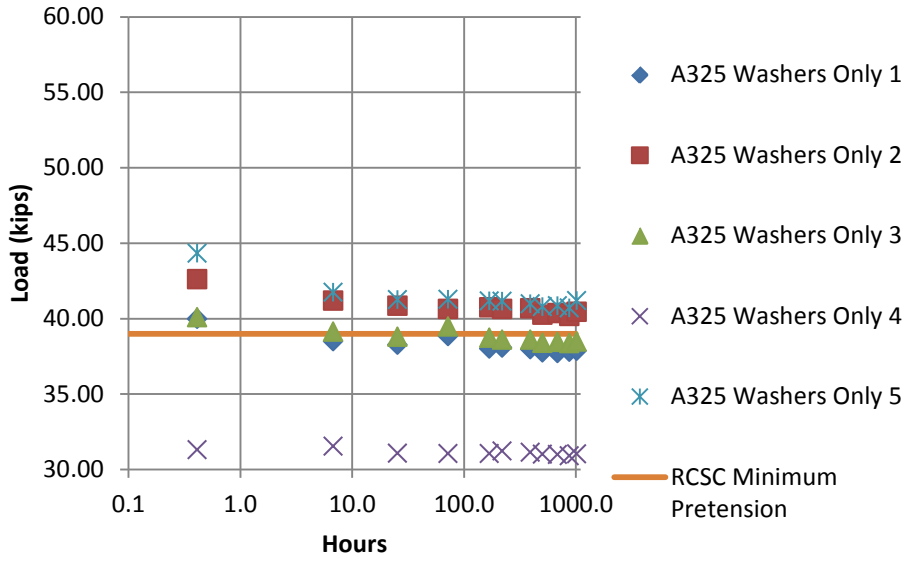
Figure 5 shows the percentage loss in tension as a function of the initial tension for each type of assembly after 42 days. The loads measured at approximately 20 minutes are used as the reference loads. While the values have some variation as a function of time, the general trends are similar at all times.

Comparison of A325 washer only vs. Type 325 Cold-worked and Annealed DTI

The measurements shown in Figure 5 shows that there is no significant difference in the behavior of the various assemblies. Rather, the data suggest the percentage loss of tension is primarily dependent on the level of initial load. The relative positioning of the trend lines through the data sets rearranges somewhat over time. For example, at 7 days, there are slightly higher losses for the Type 325 assemblies relative to the A325 washer only assemblies whereas at 21 days this order reverses with slightly higher losses for the washer only assemblies. These differences are not considered significant and the change in ordering simply reflects the scatter of the data from variations in lab conditions once the assemblies have stabilized. The magnitudes of the losses observed in all A325 assemblies are less than the range of initial loads obtained when a procedure used to replicate field installation methods was used to develop the pretension load.

Behavior of A490 Assemblies

Somewhat larger loss of initial load was found in the Type 490 DTI assemblies than in the assemblies with only washers installed in standard holes. These losses in the DTI assemblies were not considered to be of a magnitude to raise long-term performance concern, as the losses on all of the A490 assemblies (both in terms of fraction of initial load and absolute magnitude) were smaller than those found with A325 bolts. Furthermore, the losses did not result in loads below the specified minimum pretension, as previously discussed. Similar to the trend found with A325 assemblies, the magnitude of total loss is less than the range of initial loads.



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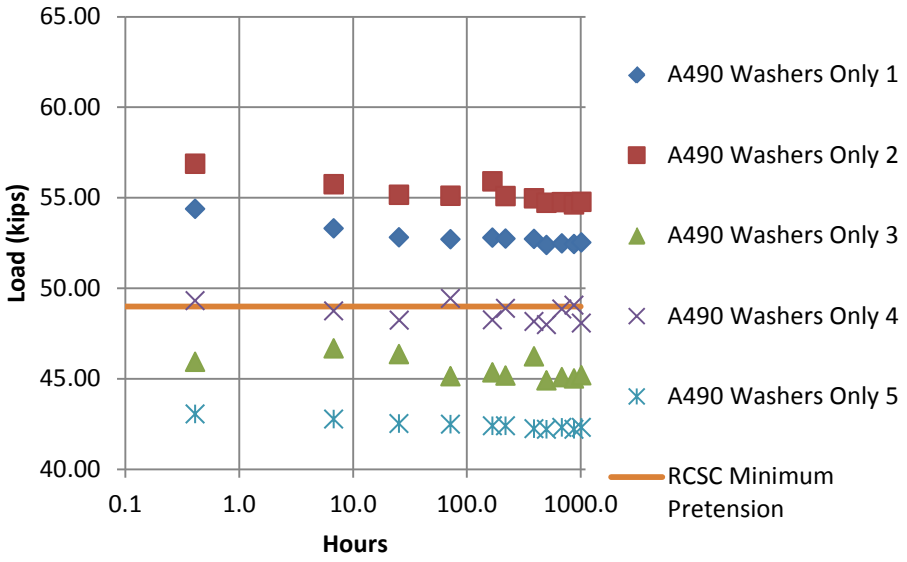
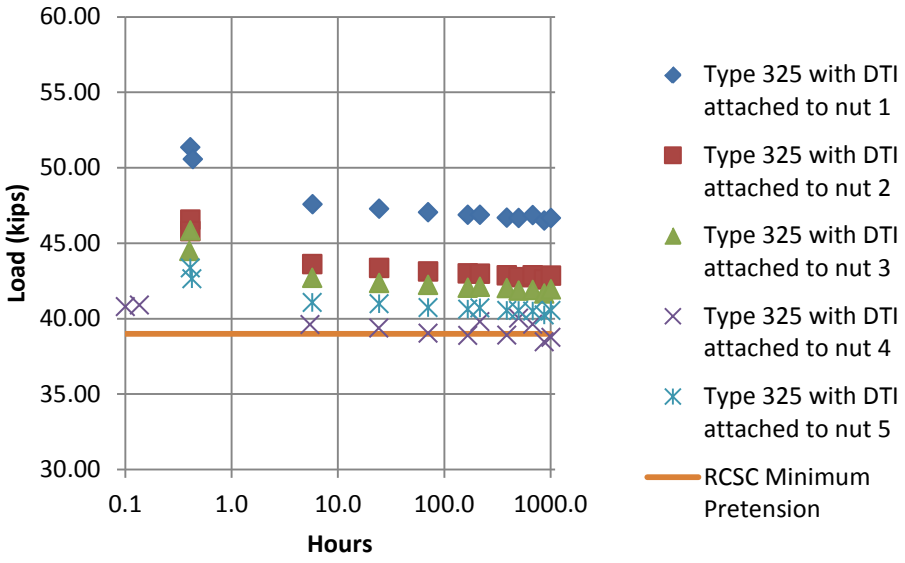


b)

Figure 3. Time history of measured bolt tension for assemblies with only washers a) A325 washer only and b) A490 washers only (tensioned with measured torque).



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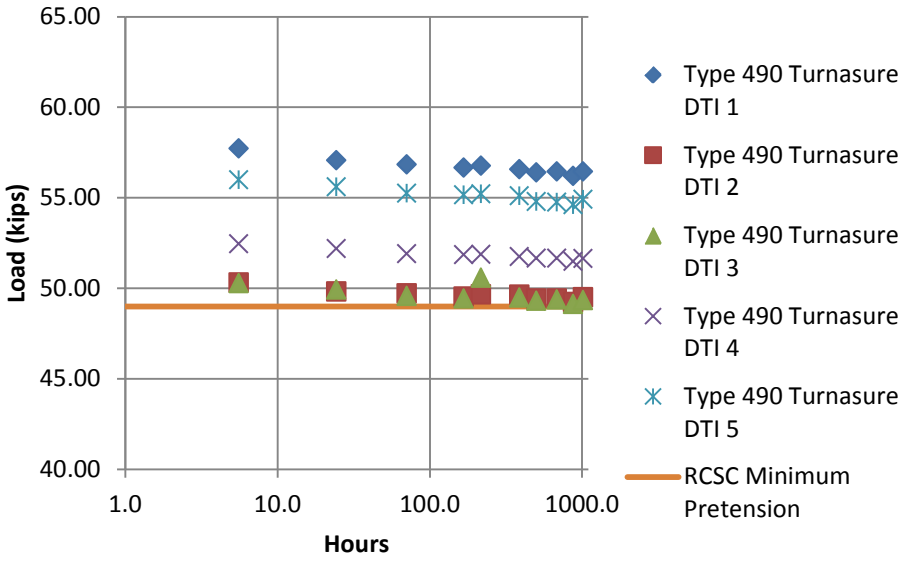

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Figure 4. Time history of measured bolt tension for assemblies with DTIs a) Type 325, b) Type 490 (tensioned with feeler gage).

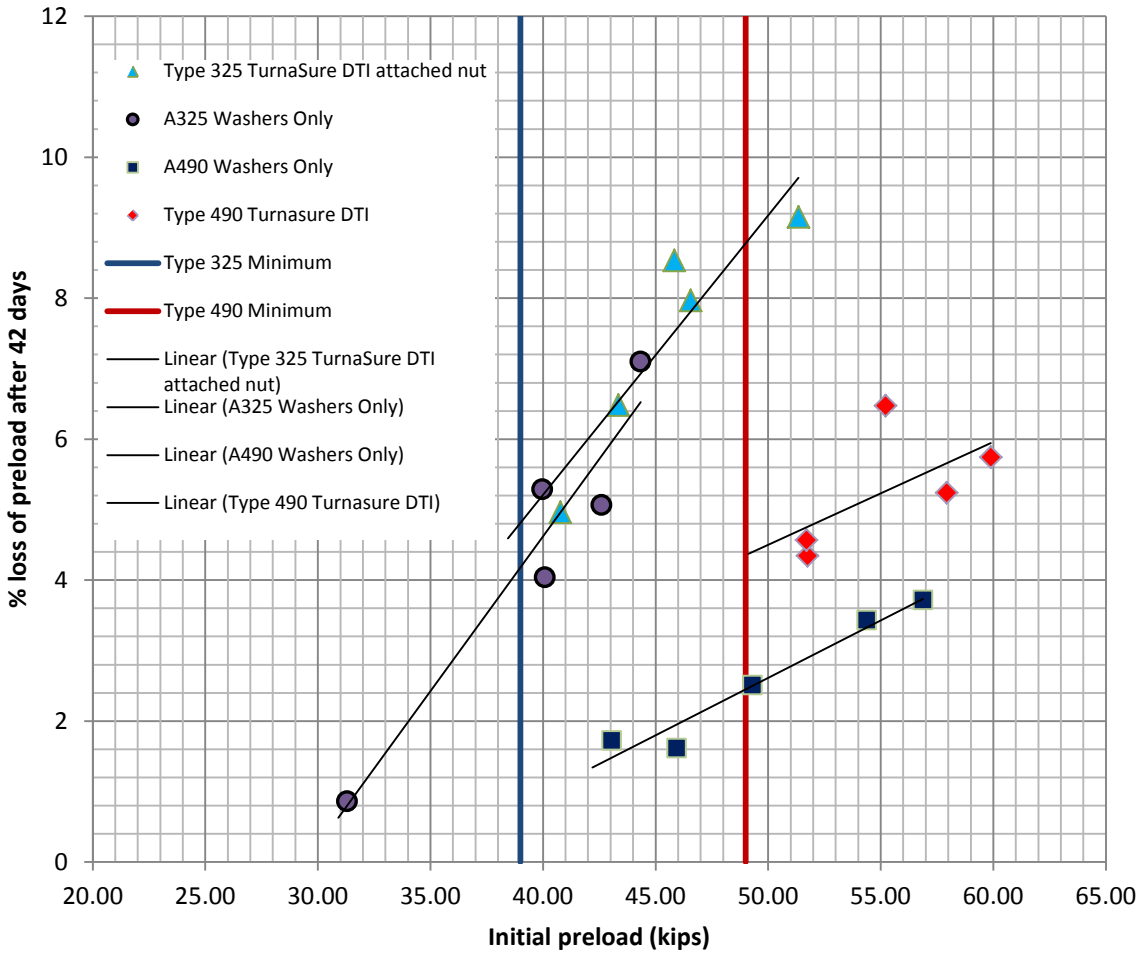

Figure 5. Percent loss of bolt tension relative to initial tension at 42 days.

Conclusions

- The loss of pretension in all bolted assemblies studied occurred primarily in the first 24 hours and bolt tensions were stable within 7 days. Time-dependent losses of tension did not result in assemblies with DTIs falling below the minimum required tension after 1000 hours of monitoring when initial tension requirements were satisfied. The total loss of tension in any assembly was less than the range of tension achieved within any assembly group tensioned using field methods.

- For bolted assemblies tested with A325 bolts, initial tension was found to be the most important predictor of creep/relaxation losses. This suggests that most of the losses occur in the bolt and/or nut, rather than the DTI or washer.

- For all bolted assemblies tested with 490 bolts, there is some effect of the DTI on the creep/relaxation losses. However, overall losses were smaller compared to assemblies with A325 bolts, suggesting that creep/relaxation might not be as significant on bolted assemblies with A490 bolts compared to A325 bolts.

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