Compression Testing of Armatherm Barrier

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Introduction:

Thermal barrier plates are adopted in beam-to-beam or beam-to-column connections to provide insulation between interior and exterior steel or concrete work to prevent excessive heat transfer due to thermal bridging. A common application is to provide a break between an exterior balcony support and interior frame. In such an application, the thermal barrier is subjected to compression, shear, and flexural loads. The purpose of this testing program was to determine whether connections with Armatherm fiber reinforced resin (FRR) thermal barrier are subject to any additional time-dependent losses of clamping force beyond the relaxation that occurs in an all-steel bolted connection. This study evaluates potential losses induced by compression loading of the thermal barrier.

Test Program:

The test matrix consisted of two tests of each of five distinct assemblage configurations. Testing on each assemblage configuration was duplicated to provide data redundancy. The configurations are based on a typical application, as suggested by Figure 1. Specific test assemblies are shown in Figure 2 and include:

- Configuration 1 - A base case of two 1/2-in. x 10-in. x 6-in. steel plates placed back-to-back and loaded in compression using four ASTM A325[1] structural bolts with standard ASTM F436[2] washers behind the nut (Plates 1 and 2);

- Configuration 2 - A second base case of a 1-in. x 10-in. x 6-in. steel plate sandwiched between two 1/2-in. x 10-in. x 6-in. steel plates and loaded in compression using four ASTM A325 structural bolts with standard ASTM F436 washers behind the nut (Plates 3 and 4);

- Configuration 3 - A duplicate of the second case dimensions, with the center steel plate replaced with an Armatherm plate of 1-in. thickness (Plates 5 and 6);

- Configuration 4 - A duplicate of the third case with the addition of 1/4-in thick x 2-1/4-in diameter thermal washers and a standard size (1-3/4-in diameter) ASTM F436 washer (Plates 7 and 8);

- Configuration 5 - A duplicate of the fourth case with the standard size ASTM F436 washer replaced with an 2-1/4-in diameter washer of equivalent hardness (Rockwell Hardness C greater than 38) (Plates 9 and 10).

The first case served to determine the anticipated load losses that would occur in the bolts in a typical installation without the presence of thermal break material. The second case provided a comparison point for losses with bolts of the same length as would be used with a thermal break. The last three cases were used to evaluate the impact of the thermal break and thermal washers on losses.

All four 7/8-in diameter structural bolts in each assembly were snugged. Then each bolt was tensioned to approximately 45,000 lbs. using the tightening sequence shown in Figure 3. The initial tension of 45,000 lbs is approximately 15% above the RCSC minimum pretension[3]. The bolt tension was measured using ultrasonic means[4]. For the tests considered, the measured initial bolt tension was between 42,700 lb and 48,000 lb. Once the tightening sequence was completed, the tension is each bolt was re-measured. The tension in the bolts was then monitored periodically until the clamping force was stable with respect to time.

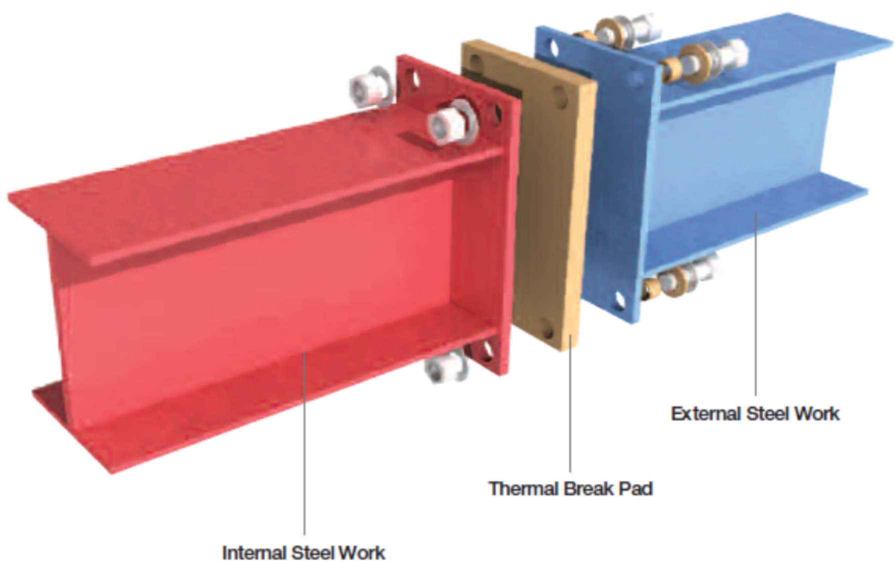

Figure 1. Schematic of typical installation (image provided by Armadillo Noise and Vibration Control).

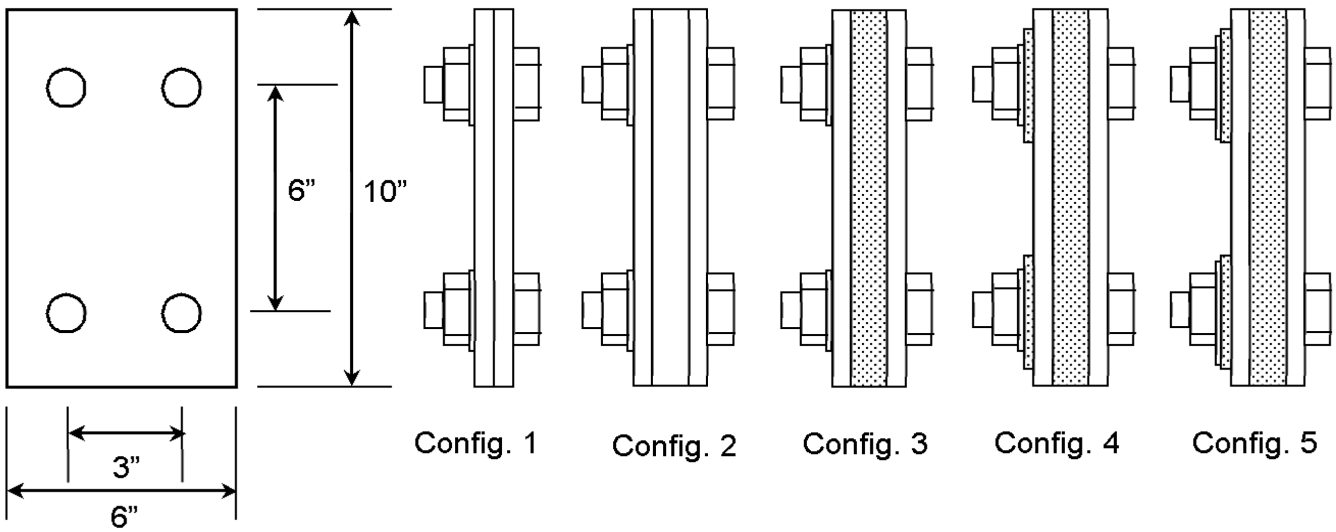

Figure 2. Test Assemblies (Armatherm material shaded).

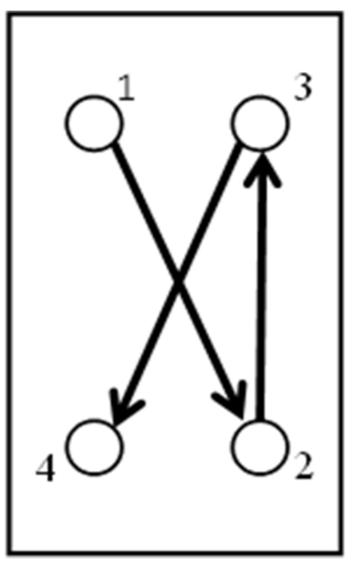

Figure 3. Bolt tensioning sequence.

Results and Discussion:

Forces in the bolts measured at two different times are used as reference point for losses. First, the total of the tension force in each bolt immediately after it was tightened were added together to determine the initial total load. For all but Bolt 4 in an assembly, this measurement was made prior to completion of the entire tensioning sequence. The initial total load on any single plate is within +/- 2.1% of the average for all 10 plates. Note that losses in bolt tension that occur due to time dependent bolt behavior or group effects means that this initial total load is never actually applied to the plate. Second, once the sequence of all four bolts was tightened, the force in each bolt in the assembly was then re-measured and the total of these values is the post-sequence clamping load. The bolt forces were then monitored over time until they stabilized. The total of the four stabilized bolt forces for each bolt is referred to as the stabilized clamping force. Results from the 10 plates are summarized in Table 1. The loss of clamping force, relative to the sum of initial bolt tensions, for each plate is shown in Figure 4. In this figure, results are shown as the losses occurring during tightening and the losses that occur after completion of the tightening sequence (both measured relative to the sum of the initial bolt tension). The percent loss of load measured relative to the post-sequence clamping force is shown in Figure 5.

The first seven days (168 hours) of data from individual bolts on all assemblies is shown in Figure 6. Time-dependent change in total clamping force (the sum of the force in all four bolts within an assembly) for each of the assemblies over longer time periods are shown in Figure 7. In all assemblies, the total clamping force dropped noticeably over the first three days after tightening and was stable within seven days in all test assemblies and in most cases was stable within four days. As seen in Figure 7, there were no significant changes in total clamping force for any assembly after seven days.

Table 1: Summary of data from testing.

Plate Config.	Plate	Sum of Initial Bolt Tension (lbs)	Post-Sequence Clamping Load (lbs)	% loss from initial tensioning	Stable Total Clamping Load (lbs)	% loss from initial tensioning	% loss from post-sequence load
1	1	181300	173450	4.3	114180	37.0	34.2
	2	176930	169960	3.9	119955	32.2	29.4
2	3	177920	173200	2.7	125500	29.5	26.8
	4	180870	176150	2.6	139037	23.1	21.1
3	5	177920	173800	2.3	130200	26.8	25.1
	6	176150	174400	1.0	129000	26.8	26.0
4	7	174690	153060	12.4	103840	40.6	32.2
	8	177400	160090	9.8	106000	40.3	33.8
5	9	175770	163875	6.8	112490	36.0	31.4
	10	175230	157925	9.9	118450	32.4	25.0

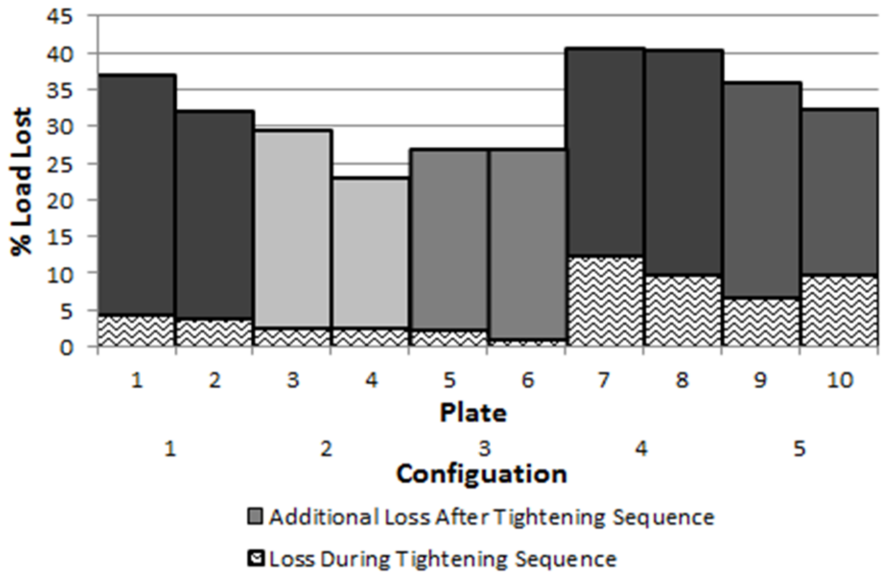

Figure 4. Loss of clamping force relative to sum of initial bolt tensions.

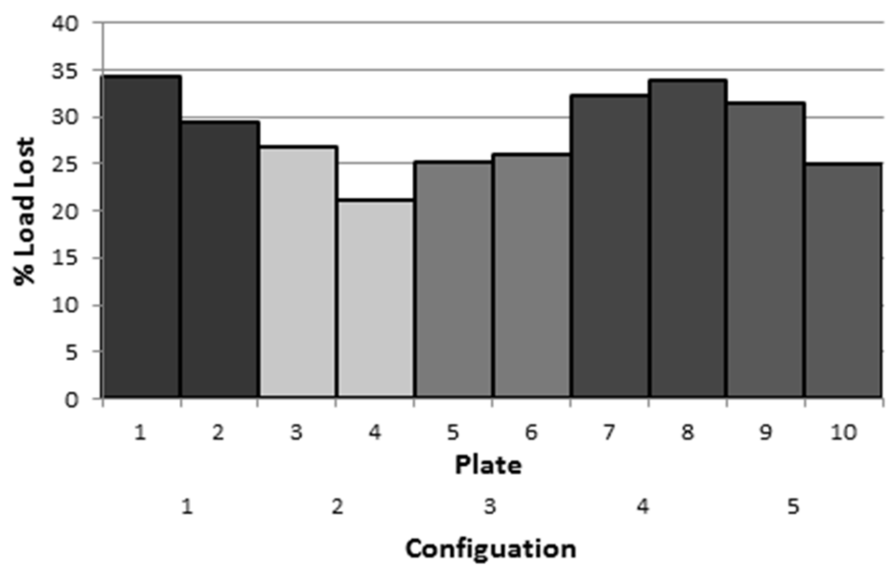

Figure 5. Loss of clamping force relative to Post-Sequence Clamping Load.

Configuration 1 represents a connection assembly without thermal material. Configuration 3 is simplest connection considered that included thermal barrier material. The loss of clamping force was smaller in Configuration 3 compared to Configuration 1, both during the tensioning sequence and after the tensioning sequence. The smaller loss of clamping force in Configuration 3 is attributed the longer bolt length. It is speculated that plastic deformation in the threads is the predominate mechanism for the loss of clamping force in the bolts in the connections. This plastic deformation is independent of bolt length and therefore the loss of force is greater for a shorter bolt length than it is for a longer bolt length.

Similar losses are observed for Configuration 2 as Configuration 3. This supports the suggestion that the bolt length is the primary reason for the reduced loss in clamping force, as the bolt lengths are identical for these two configurations, yet the plate material is different. This comparison suggests that the insertion of the plate of thermal barrier material into the connection does not affect the clamping force in either the short or long term.

Configuration 4 introduces a 2-$^1/_4$ in. diameter by ¼-in. thick thermal washer covered by a standard 1-$^3/_4$-in. diameter F436 structural washer in addition to the 1-in. thick thermal plate. The addition of the thermal washers resulted in significantly higher loss of clamping force during the tensioning sequence. The losses during tightening were approximately 4% in Configuration 1 versus 11% in Configuration 4. The additional losses that occurred after completion of the tensioning sequence were comparable to Configuration 1. The total losses relative to the sum of the initial bolt tension were elevated relative to Configuration 1. The higher compressive stresses, combined with less radial constraint on the thermal washer are the likely causes of the higher losses during the initial tensioning sequence.

The larger losses of clamping force seen in Configuration 4 were partially mitigated by the use of a larger, 2-$^1/_4$-in. diameter F436 structural washer over the thermal washer. The larger washer reduced the stresses on the washer and provided additional radial constraint. The losses during the initial tensioning were reduced to an average of 8.4%. The losses after the tensioning sequence was completed were smaller than in Configuration 1, resulting in the total loss of clamping force being approximately the same for Configurations 1 and 5.

Conclusions:

Assemblages containing the Armatherm barriers but not thermal washers yielded lower losses of clamping force during both the tightening sequence, and until stabilization of the load, compared to that of baseline all-steel assemblages. However, inclusion of the thermal washer resulted in load losses between initial tightening and stabilization that were larger than found in the baseline all-steel assemblages, and larger than found when a 1-in steel or 1-in thermal plate was included. The losses of clamping force between initial tightening and stabilization for the connections containing the Armatherm washer was found to be affected by the size of the steel washer which covered the Armatherm washer in the connection. Using a larger cover washer reduced the losses during tightening but not to the point they were equivalent to not using a thermal washer. The total loss of clamping force measured from the sum of the initial tensioning force until a stable force was achieved were approximately the same for the base configuration all-steel connection (Configuration 1) and the configuration with thermal barrier, thermal washers and larger diameter hardened washers (Configuration 5).

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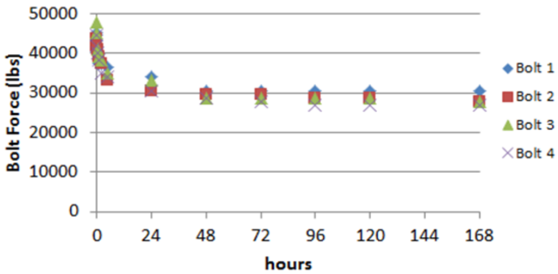

Plate 1 - two 1/2", no filler plate

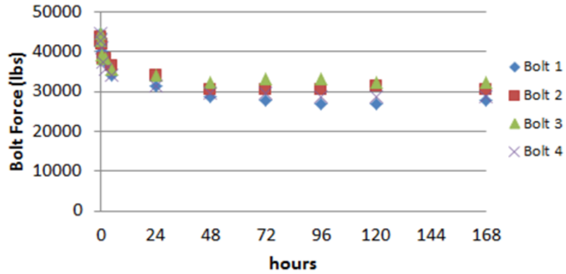

Plate 2 - two 1/2", no filler plate

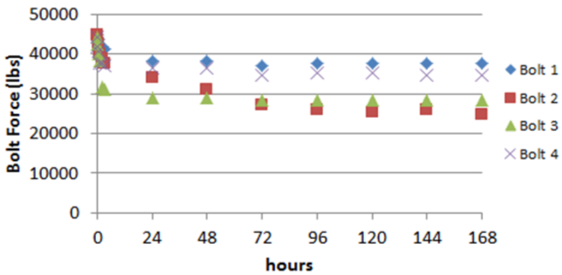

Plate 3 - two 1/2", 1" steel filler plate

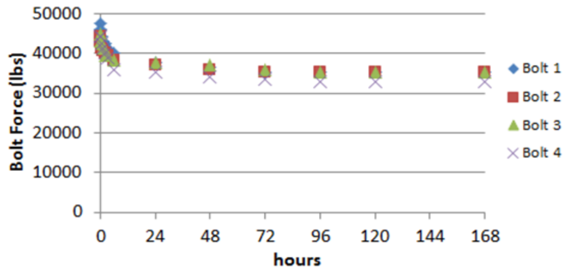

Plate 4 - two 1/2", 1" steel filler plate

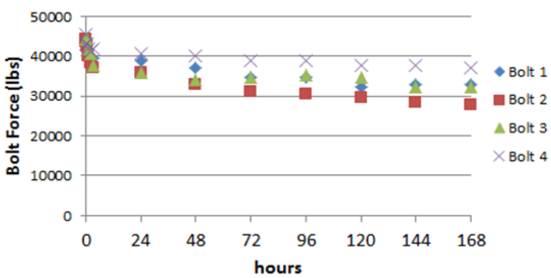

Plate 5 - two 1/2", 1" Armatherm filler plate

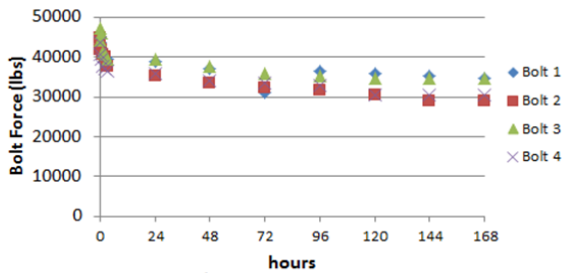

Plate 6 - two 1/2", 1" Armatherm filler plate

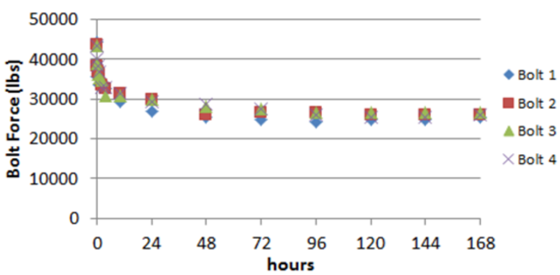

Plate 7 - two 1/2", 1" Armatherm filler plate, Armatherm washers

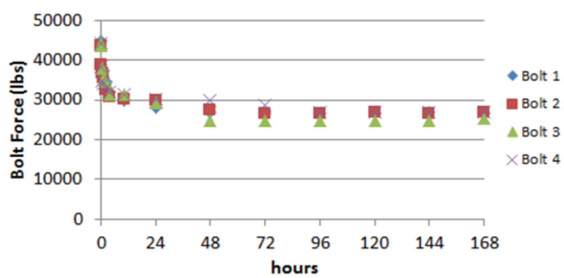

Plate 8 - two 1/2", 1" Armatherm filler plate, Armatherm washers

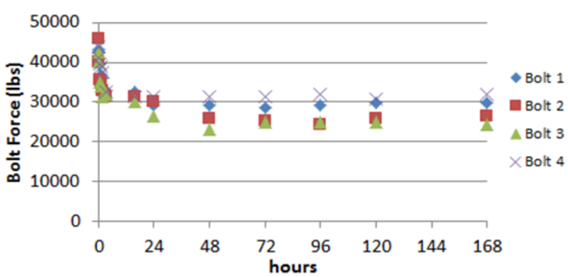

Plate 9 - two 1/2", 1" Armatherm filler plate, Armatherm washers, large diameter hardened washer

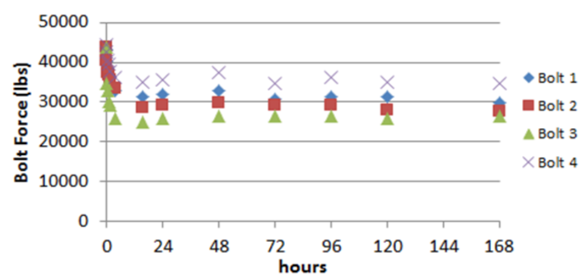

Plate 10 - two 1/2", 1" Armatherm filler plate, Armatherm washers, large diameter hardened washer

Figure 6. Loss of individual bolt tension over first seven days.

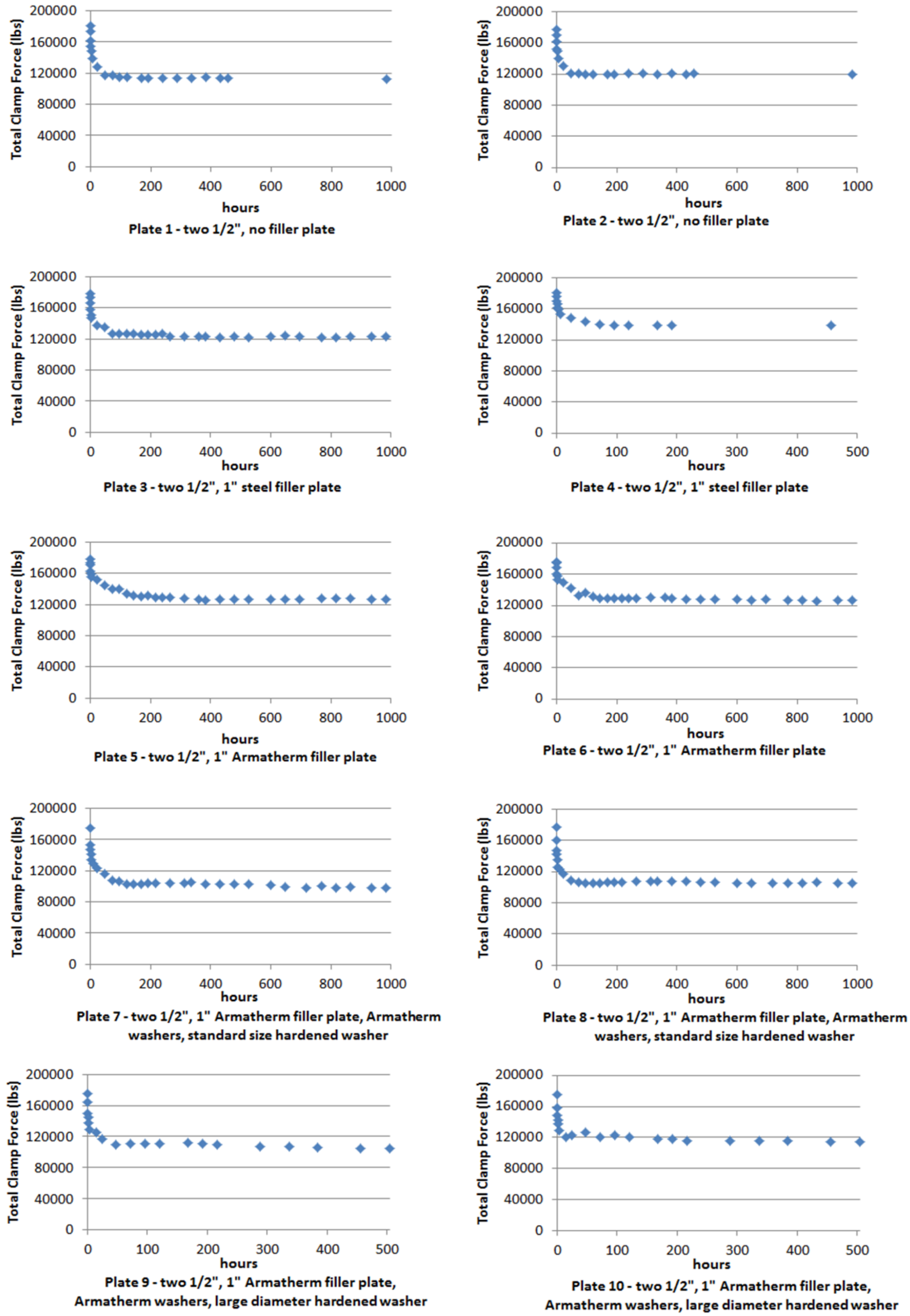

Figure 7. Time dependent loss of total clamping force.

References

1. ASTM International (2010). ASTM Standard A325-10 (2010) "Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength," ASTM International, West Conshohocken, PA, www.astm.org.

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3. Research Council on Structural Connections (2009), *Specification for Structural Joints Using High-Strength Bolts* December 31, 2009, Research Council on Structural Connections, Chicago, IL

4. ASTM International (2006). ASTM Standard E1685 - 00(2006) "Standard Practice for Measuring the Change in Length of Fasteners Using the Ultrasonic Pulse-Echo Technique," ASTM International, West Conshohocken, PA, www.astm.org.