NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

May 8, 2018

MATERIALS LABORATORY FACTUAL REPORT Report No. 18-004

A. ACCIDENT INFORMATION

Place	:	Millersville, Pennsylvania
Date	:	July 2, 2017
Vehicle	:	Natural gas mechanical tapping tee
NTSB No.	:	DCA17FP006
Investigator	:	Roger Evans (RPH)

B. COMPONENTS EXAMINED

Exemplar mechanical tapping tee assemblies.

C. DETAILS OF THE EXAMINATION

As-received

Figure 1 shows a photograph of one of three new exemplar Permalock® mechanical tapping tee assemblies that were tested by the Safety Board Materials Laboratory. The tee assemblies used in the testing were new and never installed. Tests were conducted to determine typical torque values for installing the Nylon bolts, typical torque values to install the locking sleeve, and the force to pull out an installed tower portion from the main. The exemplar tee assemblies were manufactured by Perfection Corporation, same model tee assembly as the one involved in the accident (see Materials Laboratory Factual Report 18-003), with the exception that the outlet portion for each tee assembly was for 1-inch CTS service pipe. Three new exemplar tee assemblies were used in the experiment and they were arbitrarily assigned an identification name, “A”, “B”, and “C”. Table 1 shows the designated name for each exemplar tee assembly, date of manufacture for the tee assembly (as marked on the tower), size specified for the main and specified for the outlet diameter size.

Each exemplar tee assembly was installed on a 2-inch IPS nominal diameter “Aldyl®” polyethylene polymer sample length, cut from the same main involved in the accident. The main was supplied by UGI in thirty-inch segments and contained a curvature that was similar to the main involved in the accident. Two tee assemblies were installed at the top dead center (TDC) of the main segment, and one tee assembly was installed on the main so that the outlet portion was facing the outside curve at a tilt angle of approximately 17 degrees relative to the top dead center of the main (same angle as the tee involved in the accident).

Each tee assembly was shipped in a sealed, transparent, plastic bag complete with written installation instructions and a depth tube. The cutter assembly and locking sleeve were installed using the Elster-Perfection written installation instructions that were supplied with the tee assembly, see Appendix A.

Safety Board Materials Laboratory Examination Group

Between October 31 and November 2, 2017, the following individuals participated in the installation and testing of three new exemplar tapping tee assemblies at the Safety Board's Materials Laboratory in Washington, D.C.:

Frank Zakar	Group Chairman	NTSB
Edward Komarnicki	Member	NTSB
Max Kieba	Member	PHMSA
Zaid Obeidi	Member	PHMSA
Joshua Arnold	Member	PHMSA
Robert Biggard	Member	Pennsylvania Public Utility Commission
Chester Wentz	Member	UGI Utilities
Mark Connors	Member	UGI Utilities

Follow-up work continued and was completed after departure of the group members.

Installation of Nylon Bolts with "Minor" and "Moderate" Torque

Nylon bolts for each tee assembly were assigned a number between "1" and "4", the same designation that corresponded to those involved in the accident (see Materials Laboratory Factual report 18-003), and orientation as shown in the photograph in table 2. The Nylon bolts for each tee were specified as the same material and size as those involved in the accident. The written instructions for installing the tee assembly indicated that the Nylon bolts are to be tightened until the corners touch using a cross over tightening pattern.

For the purpose of this report, torque values applied to the Nylon bolts were categorized as "minor" or "moderate", as indicated in table 2 and table 3. "Minor" and "moderate" applied torque values are relative terms. It was understood that application of torque for tightening a Nylon bolt using hand tools can vary greatly between operators. To reduce variation, all the bolts were installed by the same operator.

The Nylon bolts in the "minor torque" category were tightened using hand tools until the corners touched, as indicated by the tee assembly manufacturer's written instructions. In this scenario, the Nylon bolts were installed using a cross over tightening pattern, in the bolt sequence 2-3-1-4, to balance the stress applied to each Nylon bolt. The Nylon bolts were cycled through this sequence repeatedly, to maintain parallelism between mating halves of the tee, until the corners of the tee contacted each other. While tightening a Nylon bolt, a piece of paper (used as a feeler gage) was slid back and forth between the mating halves of the tee at the respective tee corner of the tee until resistance was felt in the moving paper. At that point the paper was slipped out of the joint at the corner, and no additional torque was applied to the Nylon bolt.

The Nylon bolts in the "moderate torque" category were tightened using hand tools until the corners touched, as indicated by the manufacturer's written instructions. Additional torque was applied using hand tools until the operator felt resistance, indicating the connection was tight. Torque was applied continuously and uninterrupted to one Nylon bolt until tight, as described above. The torque application was moved to the next Nylon bolt in the sequence 2-3-4-1. This approach was considered an aggressive installation scheme that subjected each Nylon bolt to one continuous and sudden application of manually applied torque stress, as opposed to repeated slow and gentle application of torque stress.

As indicated in table 2, the tower portion of tee assembly “B” was installed at the TDC of the main and the Nylon bolts were tightened with minor torque. The tower portion of tee assembly “A” was installed at the TDC of the main with the exception that moderate torque was applied to the Nylon bolts. The tower portion of tee assembly “C” was installed on the main so that the outlet portion was facing the outside curve at a tilt angle of approximately 17 degrees relative to the top dead center of the main and the Nylon bolts were tightened with minor torque. All the main segments were pressurized with compressed air to a pressure of approximately 56 pounds per square inch gauge (psig), same as the operating pressure of the main involved in the accident. After each tee assembly was attached to the main, they were checked for leaks using leak detection fluid. No leaks were detected after each tee assembly was attached to the main.

The locking torque and release torque values for each Nylon bolt were measured and are shown in table 2. For the category of Nylon bolts where minor torque was applied, the locking torque values measured as high as 31 inch-pounds (in-lbs), whereas, for Nylon bolts where moderate torque was applied the torque values measured as high as 70 in-lbs. The Nylon bolts were disassembled in the reverse order that they were installed. As an example, the last installed Nylon bolt was the first bolt to be disassembled. For the category of Nylon bolts where minor torque was applied, the release torque values measured as high as 30 in-lbs, whereas, for the category of Nylon bolts where moderate torque was applied measured as high as 49 in-lbs.

Installation of Bolts with Abusive Application of Torque

After installation of the tee assemblies was completed, certain bolts were intentionally subjected to additional torque, well beyond that which is necessary to achieve a tight installation and is accordingly categorized as abusive. Nylon bolt “1” from tee assembly “B” was turned several more times in the clockwise direction. The application of abusive torque was terminated at a random position, when the torque measured 88 in-lbs. At this point the corner post for this bolt was examined. Visual examination of the corner post for this Nylon bolt revealed the corner post was crushed, exhibited compression deformation, as shown in figures 2 and 3. This exercise was repeated for bolt “4” from tee assembly “B”, which was subjected to continuous torque until thread stripping occurred. An 84 in-lbs compression damage occurred at the corner post, and at 89 in-lbs, thread stripping occurred. Application of additional torque to the Nylon bolt beyond this peak torque resulted in continuous reduction of measured torque values, referred as thread stripping. The test was terminated when the measured torque values was reduced to 33 in-lbs. A summary of the measured locking torque for all the tested Nylon bolts are shown in table 3.

Examination of corner posts that were subjected to application of abusive torque revealed the bottom end of a Nylon bolt extended further from the tee base than Nylon bolts that were installed per manufacturer's written installation instructions (typically between 0.14 inch and 0.17 inch). The bottom end of the bolt "4" from tee assembly "B" extended as much as 0.38 inch below the base portion of the tee.

Laboratory Induced Fracture of Nylon Bolts

Experiments were conducted in the laboratory with the intent of causing a Nylon bolt to fracture by overstress, using three different approaches. Nylon bolts from tee assembly "C" that were subjected to "minor" application of torque were selected for destructive testing of the Nylon bolts.

In the first laboratory-induced Nylon bolt fracture experiment, the threaded end of a Nylon bolt was secured to a bench vice, by squeezing the threaded end between the grips of a bench vice. An Allen socket wrench (key) was inserted into the socket in the head portion of the Nylon bolt was turned clockwise using hand tools. At approximately 10 foot-pounds (ft-lbs) [120 in-lbs], the Allen key eventually rotated within the socket of the Nylon bolt head causing deformation in the socket. In this experiment, turning the Nylon bolt with an Allen key did not cause fracture or a crack in the bolt.

In the second laboratory induced Nylon bolt fracture experiment, the threaded end of a Nylon bolt was secured to the bench vice, similar to the first experiment. The head portion of the Nylon bolt was secured to a channel lock plier. The head portion was turned approximately 90 degrees and the Nylon bolt fractured at the first full thread adjacent to the non-threaded shank by torsional overstress separation. The torque required to cause fracture was not recorded. The fracture was located approximately 0.8 inch below the head portion of the Nylon bolt. Figure 4 shows a photograph of the fracture face. Bench binocular microscope examination of the fracture face revealed evidence of fracture in the polymer matrix (Nylon) and glass fibers portions, but the definition of the fracture features were not clear. SEM examination of the Nylon bolt revealed the Nylon matrix portion showed evidence of fibrils that were elongated laterally relative to the length of the Nylon bolt consistent with shear fracture in torsion mode. The elongated fibrils covered most of the fractured glass fibers (see figure 5 and 6).

In the third laboratory-induced Nylon bolt fracture experiment, a bolt was inserted through the bore of a total of thirteen steel washers that were stacked against each other (length of approximately 1.6 inches along the axis of bolt) and a steel nut was attached to the threaded end of the Nylon bolt. The nut portion was attached to the grips of the bench vice. The head portion of the bolt was turned clockwise with hand tools using an Allen key. The head was turned multiple times until the Nylon bolt fractured at the 7th root thread (approximately 1.3 inches) from the bottom of the head. The Nylon bolt fractured at an applied torque of approximately 120 in-lbs. The Allen key remained attached to the socket in the bolt head (key did not rotate within the key socket) throughout the turning operation. Figure 7 shows a photograph of the fracture face. Bench binocular microscope examination of one face of the fracture revealed the fracture area at the center portion of the Nylon bolt extended approximately the length of one thread above the fracture plane, and appeared similar to a round cone. The definition of the fracture features was not clear when examined under the bench binocular microscope. SEM examination of the Nylon bolt revealed the Nylon matrix portion showed evidence of fibrils that were elongated parallel to the length of the Nylon bolt consistent with shear fracture in tensile mode (see figures 8 and 9). Many of the glass fiber fracture faces showed evidence of a fracture propagation direction, but the direction of fracture propagation varied from fiber to fiber.

Installation of the Locking Sleeve

The tee assemblies were installed on a main using three different size torque wrenches (4.5-inch length, 7-inch length, and 19-inch length). Table 4 shows the designated name for each exemplar tee assembly and the size of the torque wrench that was used to install the cutter assembly. Torque values were measured as a locking sleeve was forming threads into a main. The measured torque for forming threads in the main was between 120 in-lbs and 129 in-lbs, see table 4.

Also, during testing, a depth tube was placed on top of the cutting tool for each tee assembly. The manufacturer's written installation instructions indicated to place the depth tube and thread cutter assembly downward using a 5/16-inch hex wrench. Continue threading the cutter assembly downward until it becomes snug. The depth tube will be flush to 1/8 inch above the tee tower, see table 5.

Tee assemblies "A" and "C" were installed in accordance with the manufacturer's written instructions. For tee assembly "A," the cutter assembly was driven down into the pierced hole so that the top portion of the depth tube was approximately located flush (level) with the top of the tower. For tee assembly "C," the cutter assembly was driven down so that the top portion of the depth tube was located approximately 0.13 inch above the top of the tower. Table 5 shows the measured final position of the depth tube relative to the top of the tower and corresponding torque. In table 5, the symbol ">" indicates "greater than."

When threading the cutter assembly downward through the tower using a 4.5-inch or a 7-inch length torque wrench, in tee assemblies "A" and "C", respectively, it was possible to feel (differentiate) the various phases of the installation. The level of resistance could be felt in the handle of the two torque wrenches as the cutter assembly was driven down the bore of the tower. It was possible to sense changes in the resistance on the handle of the wrench as the cutter tool was piercing the main; the cutter tool was driven past the wall of the main; the locking sleeve was forming threads into the main; when the ratchet outer lip (flange) portion of the locking sleeve made contact with a manufactured flat step (referred as a stop) near the bottom of the bore; and when the cutter tool separated from the locking sleeve (breaking torque). Table 6 shows typical torque values encountered when installing tee assembly "C".

Tee assembly "B" was installed with a 19-inch length torque wrench. Changes in resistance was not felt on the wrench handle during the various phases of the installation. The cutter assembly was driven down the bore with the anticipation that resistance would be felt in the handle of the wrench when the stop was reached. This was not the case. The outer lip (flange) portion of the locking sleeve was driven below and beyond the stop, to the position indicated in table 5. This test demonstrated that the steel locking sleeve can be forced to travel beyond the stop position when using a 19-inch length wrench, and a change in resistance may not be felt in the handle of the wrench.

Once the locking sleeve for each assembly was installed, the cutter tool was retracted to be flush with the top of the tower, a position that would gasify the service line, as indicated in the manufacturer's written installation instructions.

For each completed tee installation, the open end of the main was visually examined to determine the position of the locking sleeve. Examination of the inner walls of a main revealed the locking sleeve for each tee assembly was attached to the main. Figure 10 shows the exposed end of a locking sleeve as it appears inside the main for a tee assembly that was installed per manufacturer's written installation instructions with a depth tube 1/8-inch above the tee tower. The bottom end of the locking sleeve barely extended below the inner wall of the main. Figure 11 shows the threaded portion of the locking sleeve for tee assembly "B" that was not installed per manufacturer's written installation instructions, resulting in a threaded portion of the locking sleeve that extended approximately 0.4 inch below the inner surface of the main. In tee assembly "B", the flange portion of the locking sleeve was driven past and below the stop at the bottom of the tower.

Prior to all installations, cutter assemblies were removed from each tee assembly to determine whether the cutter tool and locking sleeve could be separated from each other by hand. The cutter tool and locking sleeve for each tee assembly was separated by hand with ease (no evidence of binding between the cutter tool and the locking sleeve).

Forceful Pullout of Locking Sleeve

A test was conducted to determine the amount of tensile force that was required to pull out a locking sleeve and tower from a main installed per the manufacturer's written instructions with a tee base and Nylon bolts removed. Figure 12 shows the set-up for the testing. Tee assembly "C" was used in this experiment. Steel attachment bolts, each with a closed loop hook, were attached to the tower portion. A steel cable was passed through the closed loop hook of each steel bolt and, in turn, the other end of the cable was attached to a lifting crane. The force required to pull the locking sleeve and tower from the tee was recorded with an electronic force gage. As a tensile force was applied to the locking sleeve and tower via the cable, one side of the tower started to lift from the main at approximately 280 pounds. The force required to separate the locking sleeve and tower from the main was approximately 380 pounds. Figures 13 and 14 show photographs of the pierced hole in the main after the locking sleeve was intentionally pulled out by force, revealing evidence of thread deformation damage.

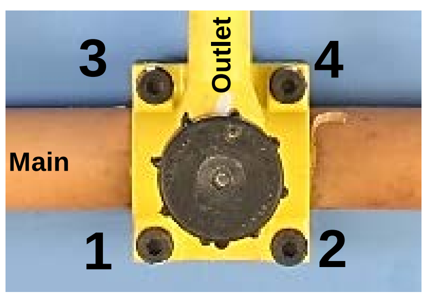
Frank Zakar
Senior Metallurgist

Table 1
Description of Exemplar Tee Assemblies and Installation Angle Relative to Main

Tee Assy.	Manufactured Date As marked on Tower (Month/Year)	Specified for Main Size IPS (Inch)	Specified for Outlet Diameter Size (Inch)	Tilt Angle of the Tower Portion Relative to the Top Dead Center of the Main (Degrees)
A	4/1999	2	1.0	0
B	4/1999	2	1.0	0
C	9/2002	2	1.0	17 Outlet was facing toward the outside curve of the main

Table 2
Locking and Release Torque Values for Nylon Bolts
(Inch-Pounds)

Tee Assy.	Locking Torque Category	Bolt							
		1		2		3		4	
		Locking Torque	Release Torque	Locking Torque	Release Torque	Locking Torque	Release Torque	Locking Torque	Release Torque
A	Moderate	70	49	51	41	69	44	68	49
B	Minor	30	-	24	-	31	-	25	-
C	Minor	30	30	24	22	27	22	30	24



Note: "-" indicates not measured

Table 3
Summary
Locking Torque Values for All Installed Nylon Bolts

Operation	Measured Torque (in-lbs)	Observation
Minor Torque	24 - 31	No damage to a bolt or corner post.
Moderate Torque	51 - 70	No damage to a bolt or corner post.
Abusive Torque	84 - 88	Application of torque in this range caused severe compression deformation to a corner post.
Thread Stripping	89	At this torque value, thread stripping occurred. Measured torque values diminished beyond this point. Compression deformation of a corner post had already preceded thread stripping.

Table 4 Greatest Torque Values as the Locking Sleeve was Forming Threads in the Main		
Tee Assembly	**Length of Torque Wrench (inches)**	**Measured (in-lbs)**
A	4.5	120
B	19	120
C	7	129

Table 5 Measured Position of Depth Tube and Measured Torque at that Depth						
Tee Assy.	**Length of Torque Wrench (inches)**	**Position of Top Portion of Depth Tube Relative to the Top of the Tower (inches)**		**Was depth tube within specified range?**	**Was resistance felt on the handle of the torque wrench when the locking sleeve made contact with the stop?**	**Measured Torque at Final Position of the Depth Tube (in-lbs)**
		Specified	**Measured**			
A	4.5	Between 0.13 above the top of the tower portion of the tee assembly and level with the top of the tower portion of the tee assembly	0	Yes	Yes	>130
B	19		0.12 below top of tower	No	No	276
C	7		0.13 above top of tower	Yes	Yes	>130

Table 6 Typical Torque Values Encountered During Installation of the Cutter Assembly for Tee Assembly "C"		
Item	**Sequence of Installation**	**Measured Torque (in-lbs)**
Cutter Tool	Piercing the wall portion of the main.	121
Cutter Tool	Travelling below and beyond the wall of the main.	24
Locking Sleeve	Forming threads into the wall of the main.	129
Locking Sleeve	With a 7-inch long wrench the greatest resistance was felt in the handle when the stop was reached. Extremely difficult to turn the handle beyond the bottom stop position.	>130
Breaking Torque	Wrench is turned counterclockwise. Torque that was required to break contact between mating ratchet teeth for cutter tool and locking sleeve.	109

Figure 1. One of the three new Permalock® mechanical tapping tee assemblies that was involved in the laboratory test program, showing bolts arbitrarily designated “1”, “2”, and “4”. The other two tee assemblies were the same model as shown in this photograph. A black tube (service pipe) was installed at the outlet port to facilitate pressure testing of the tee assembly. This is a photograph of tee assembly “C”.

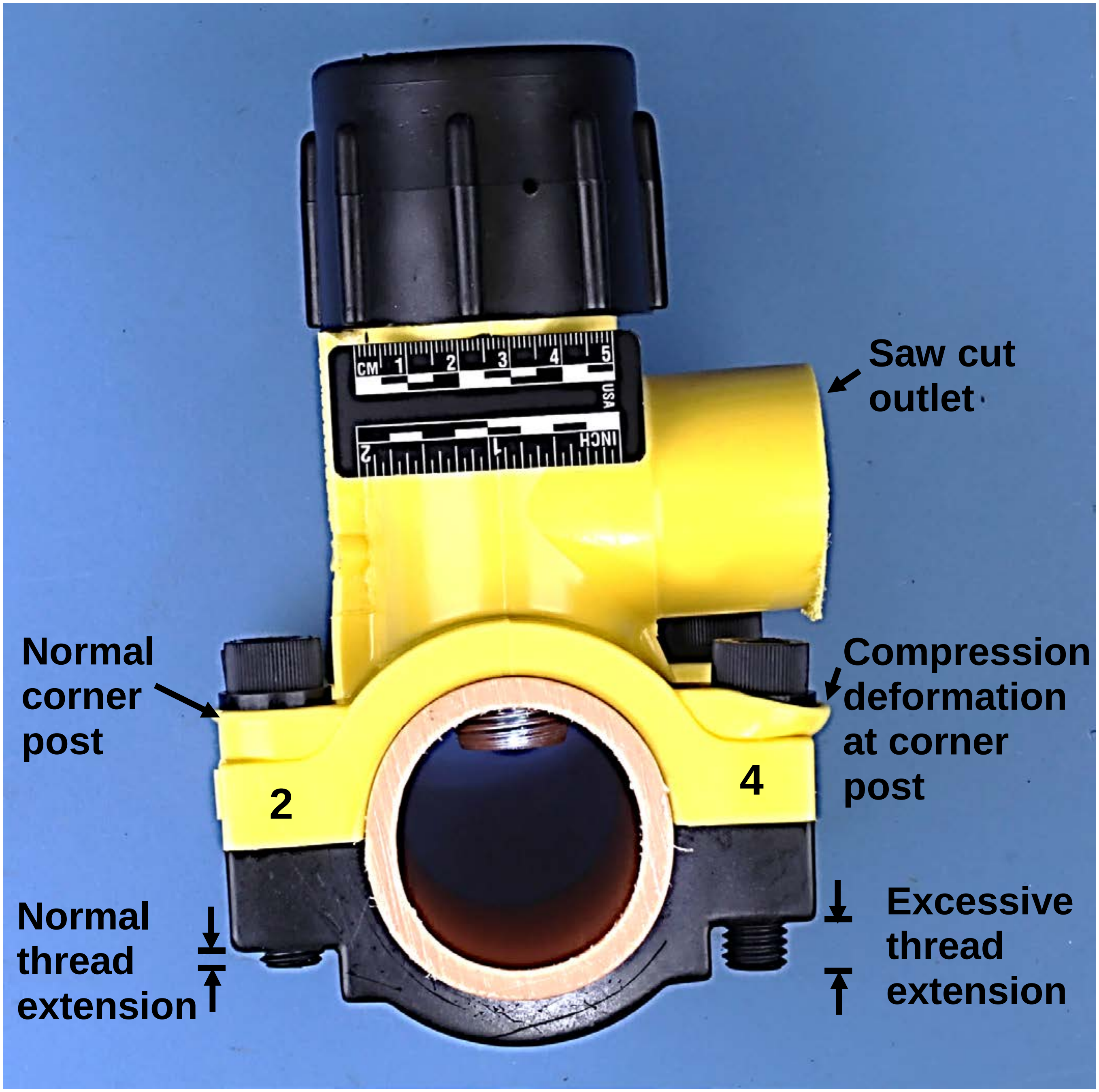


Figure 2. Photograph of the tee assembly “B” that was not installed per manufacturer instructions showing the exposed inner wall of the main in the area where the cutter tool pierced the main. The corner post for Nylon bolt “4” exhibits compression damage that resulted from applying intentional and abusive torque application to the Nylon bolt during laboratory experimentation, whereas, the corner post for Nylon bolt “2” shows no evidence of deformation when installed per manufacturer instructions. In areas of the tee assembly where the corner post exhibits compression deformation damage (Nylon bolt “4”), the threaded portion of the attachment bolt extends further down and below the base compared to areas where the corner post retained its original shape (Nylon bolt “2”).

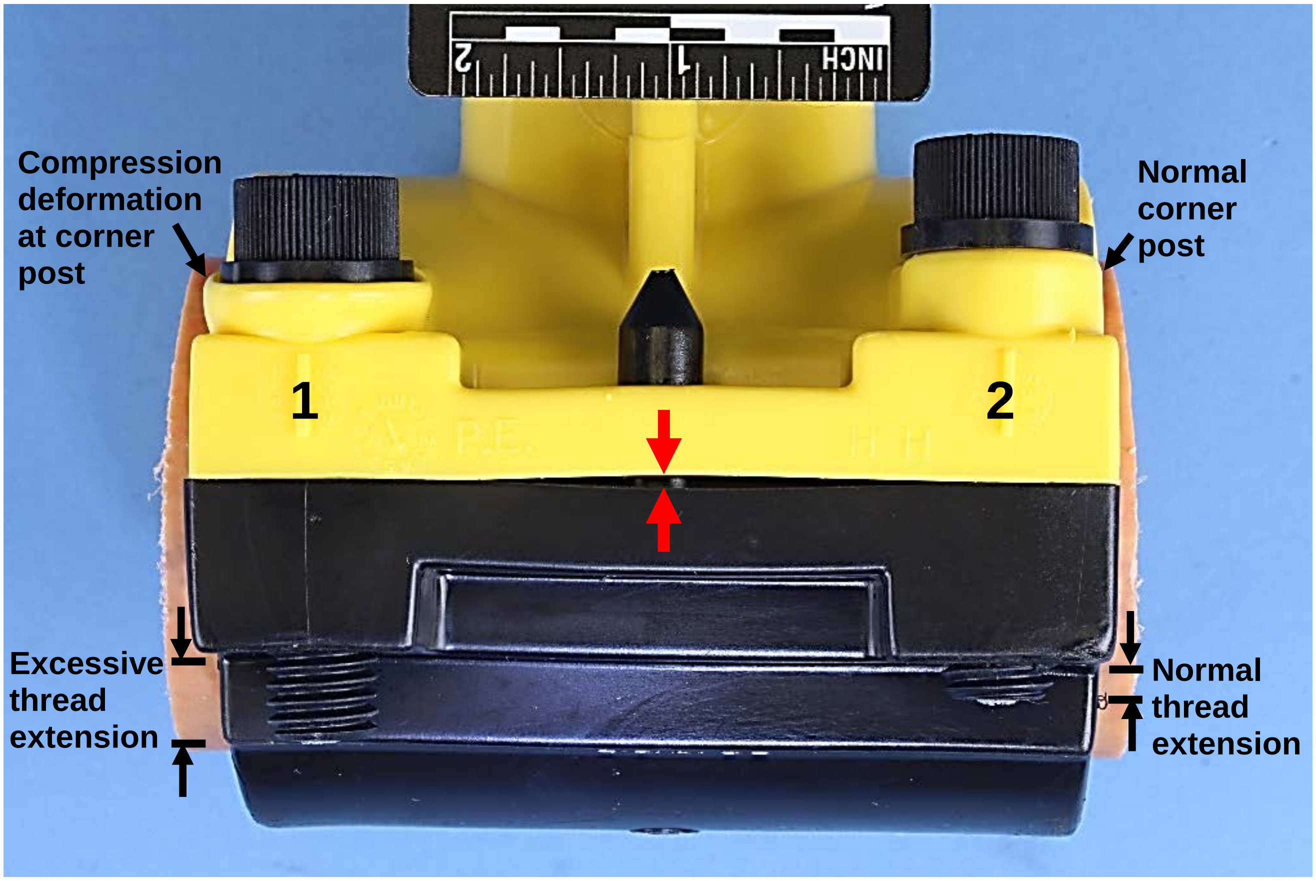


Figure 3. Tee assembly "B" showing Nylon bolts "1" and "2". Compression damage was intentionally introduced to the corner post for bolt "1" during laboratory experimentation, whereas, the corner post for bolt 2 shows no evidence of deformation when installed per manufacturer instructions. In areas of the tee assembly where the corner post exhibited compression deformation damage (bolt "1") the threaded portion of the attachment bolt extended further down and below the base compared to areas where the corner post retained its original shape (bolt "2").

NOTE: The mating halves of the tee in the area of the locating pins contained a slight manufactured bevel, see area between red arrows. The manufacturer's written installation instructions indicated that a gap between the flanges in the locating pin area is acceptable. All the assembled tee assemblies in this report exhibited evidence of a slight gap in the area of the locating pins, an acceptable condition as indicated in the manufacturer's written installation instructions.

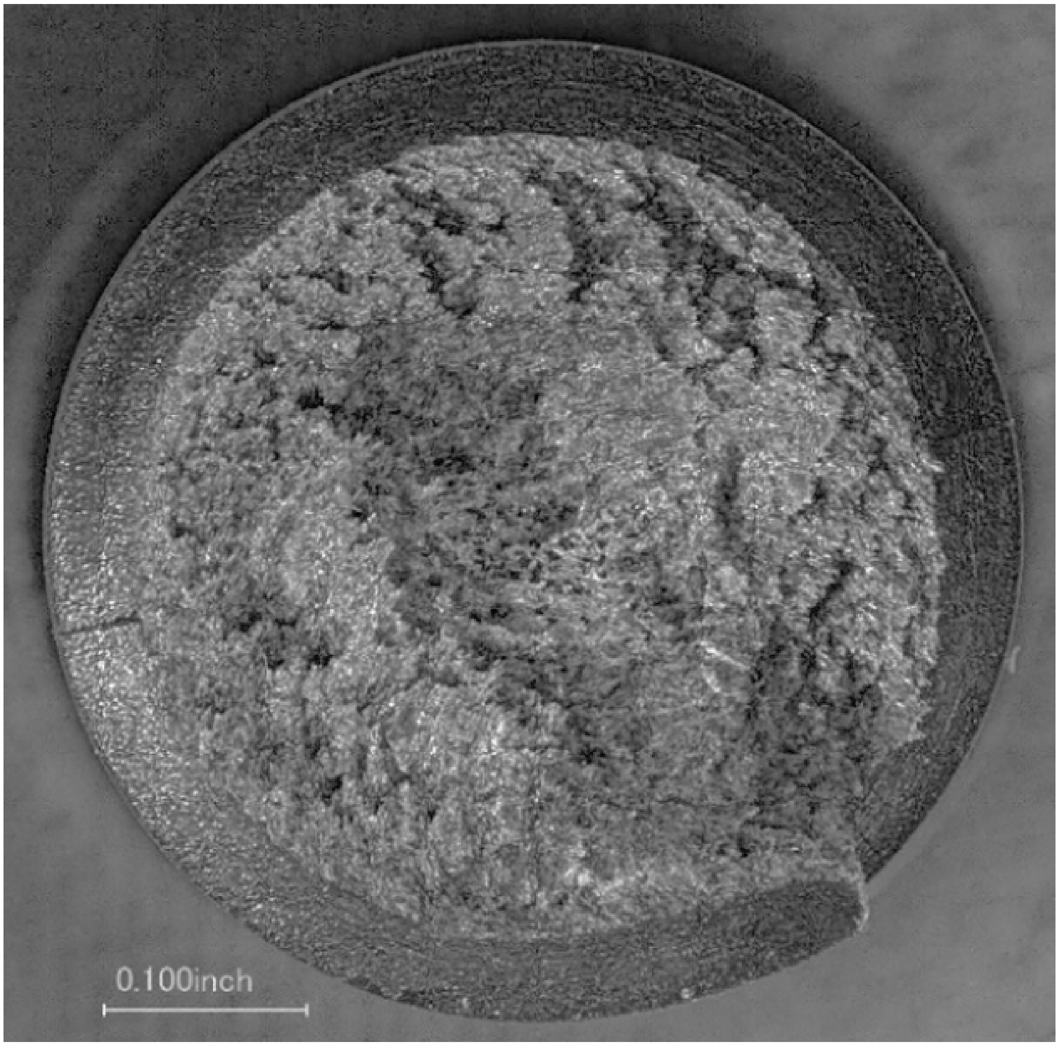


Figure 4. Optical photograph of a laboratory induced fracture in torsional overstress mode from a Nylon bolt disassembled from tee assembly “C”. The torsional deformation pattern was not obvious when examined visually with the unaided eye.

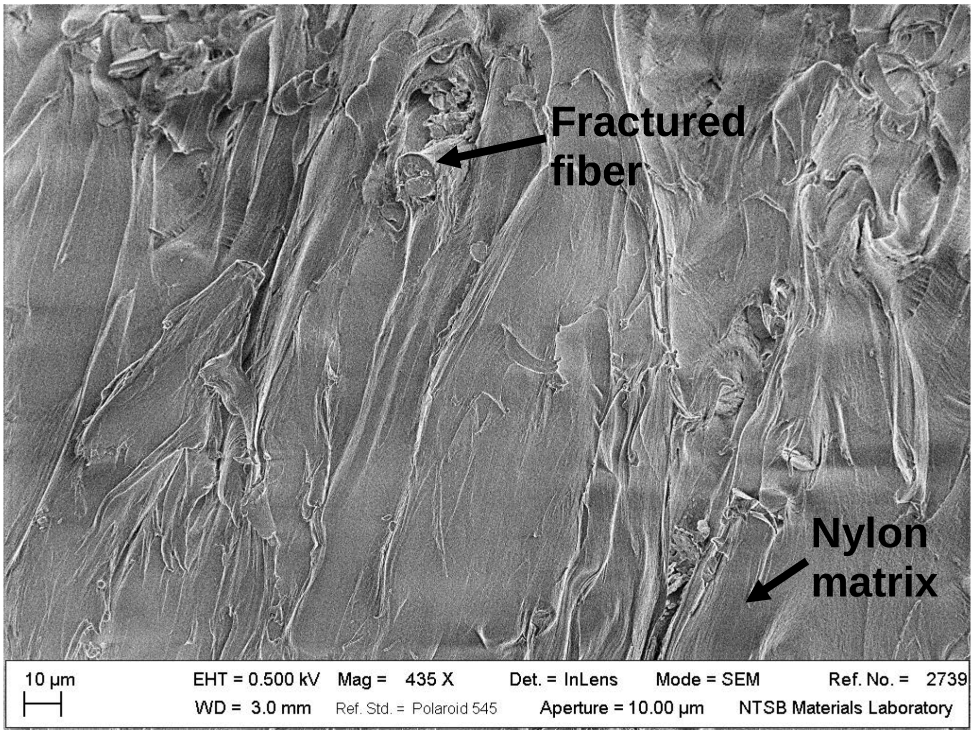


Figure 5. SEM photograph of a fracture showing elongated fibrils in the Nylon matrix that are oriented laterally to the length of the Nylon bolt consistent with an overstress fracture in torsion mode.

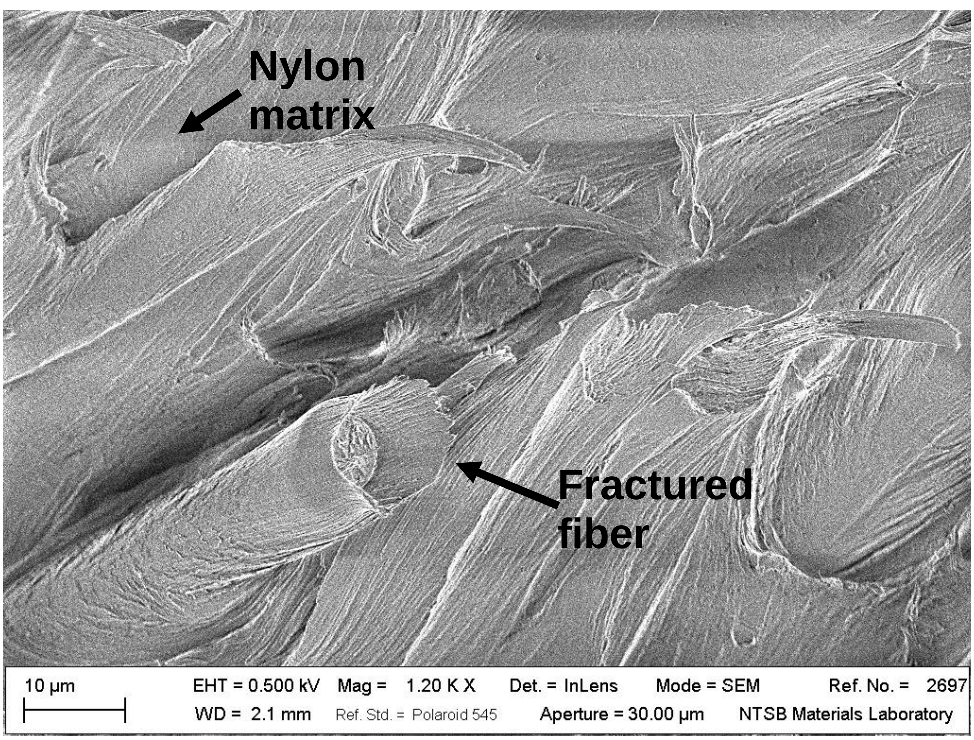


Figure 6. Higher magnification SEM photograph of a fracture showing elongated fibrils in the Nylon matrix that are oriented laterally to the length of the Nylon bolt consistent with an overstress fracture in torsion mode.

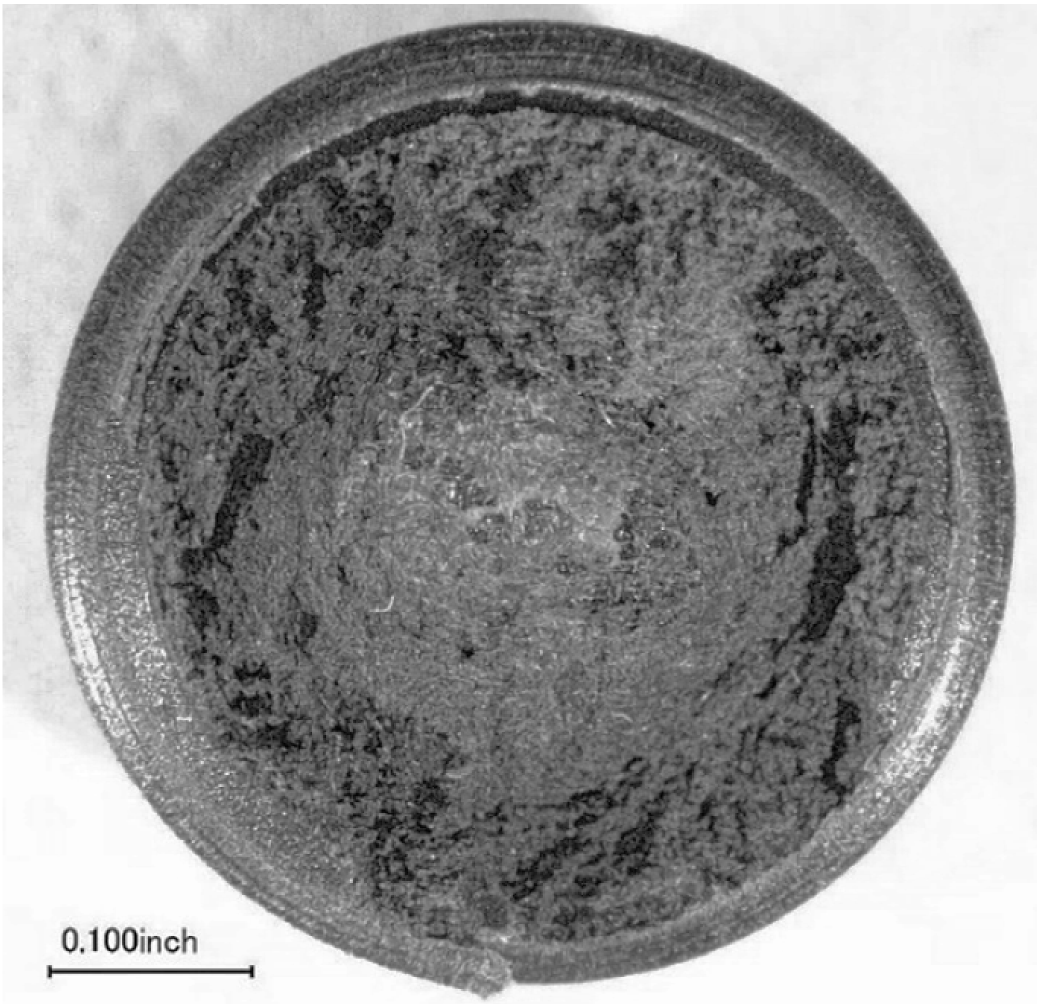


Figure 7. Optical photograph of a laboratory induced fracture in tensile overstress mode from a Nylon bolt disassembled from tee assembly “C”.

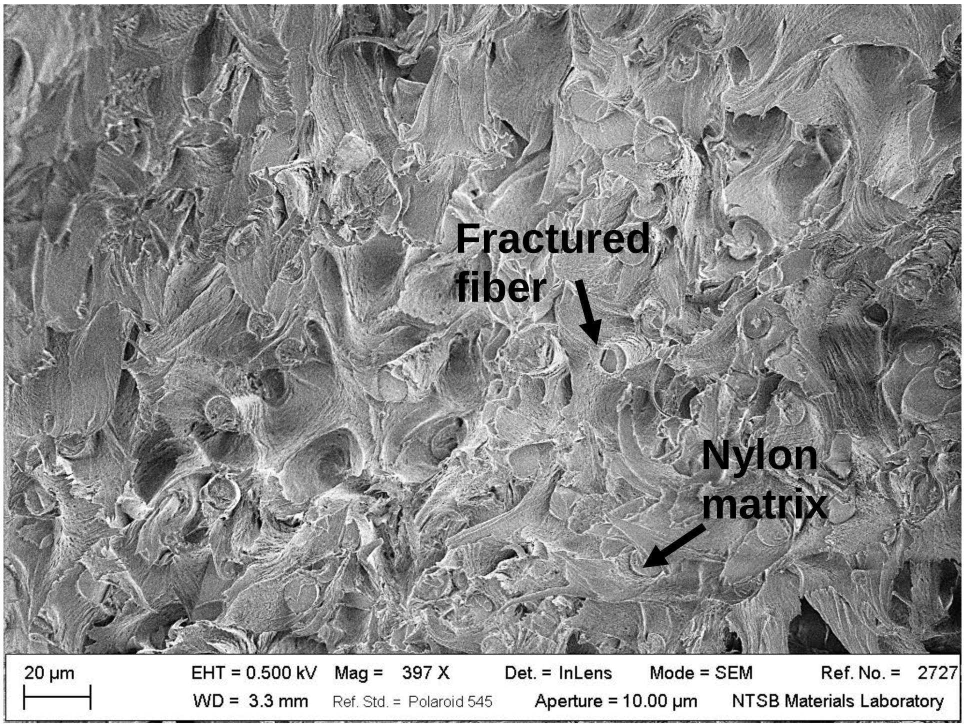


Figure 8. SEM photograph of a fracture showing elongated fibrils that are parallel to the length of the Nylon bolt consistent with an overstress fracture in tensile mode.

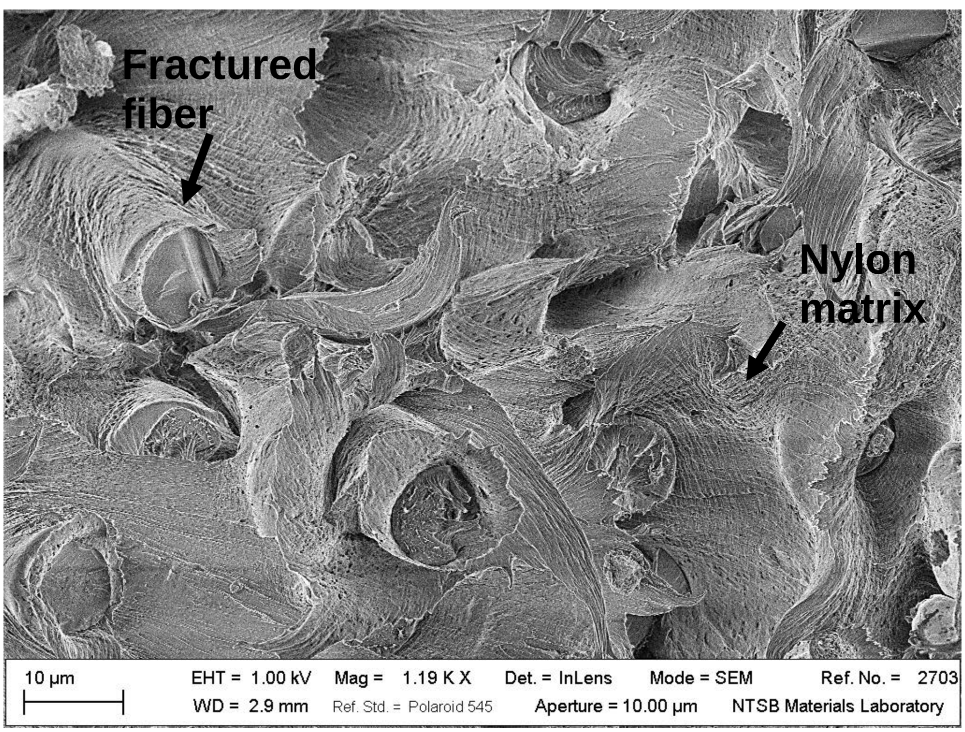


Figure 9. Higher magnification SEM photograph of a fracture showing elongated fibrils in the Nylon matrix that are oriented parallel to the length of the Nylon bolt consistent with an overstress fracture in tensile mode.

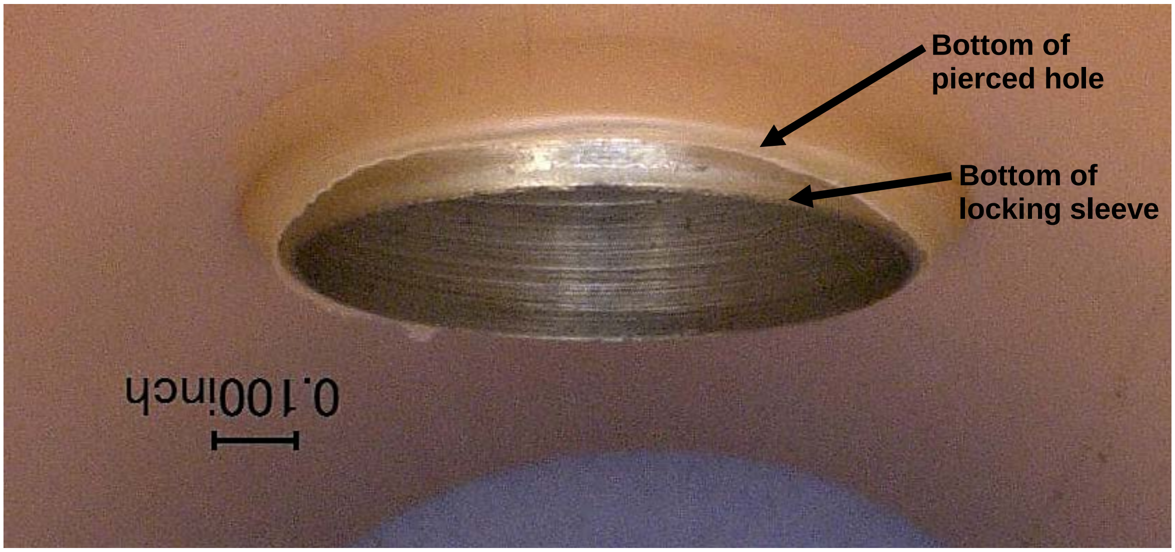


Figure 10. View looking into the inner surface of the main showing a portion of the locking sleeve thread that barely extends out of the pierced hole in the main. This is typical for a locking sleeve that was installed per manufacturer's written installation instructions. Installation of tee assembly "C" with a depth tube at 1/8-inch above the top of the tee tower.

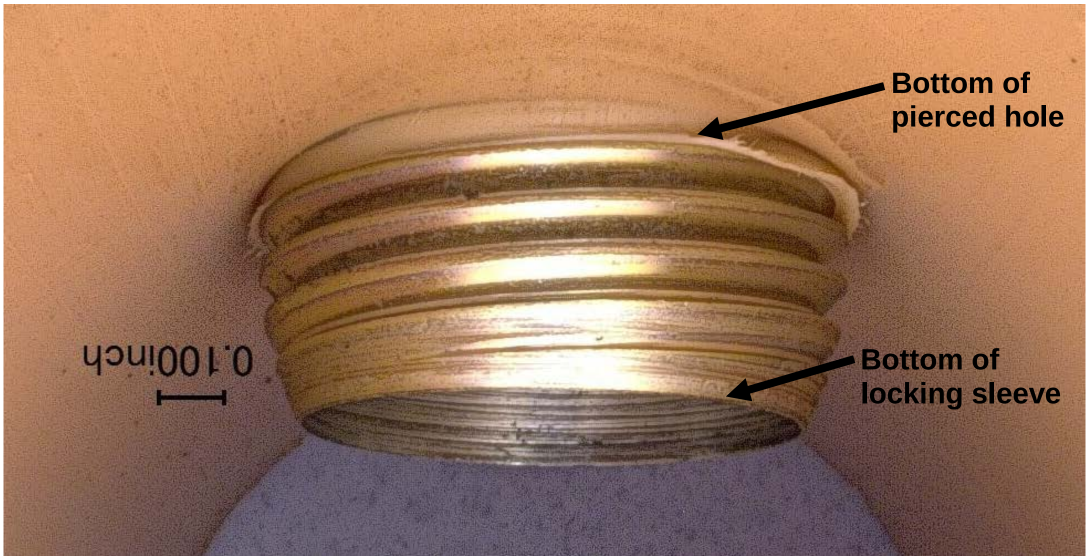


Figure 11. View looking into the inner surface of the main showing extension of the locking sleeve thread that was installed with a depth tube position at 0.12-inch below the top of the tower. A large portion of the locking sleeve thread extended out of the pierced hole in the main. Installation of tee assembly "B".

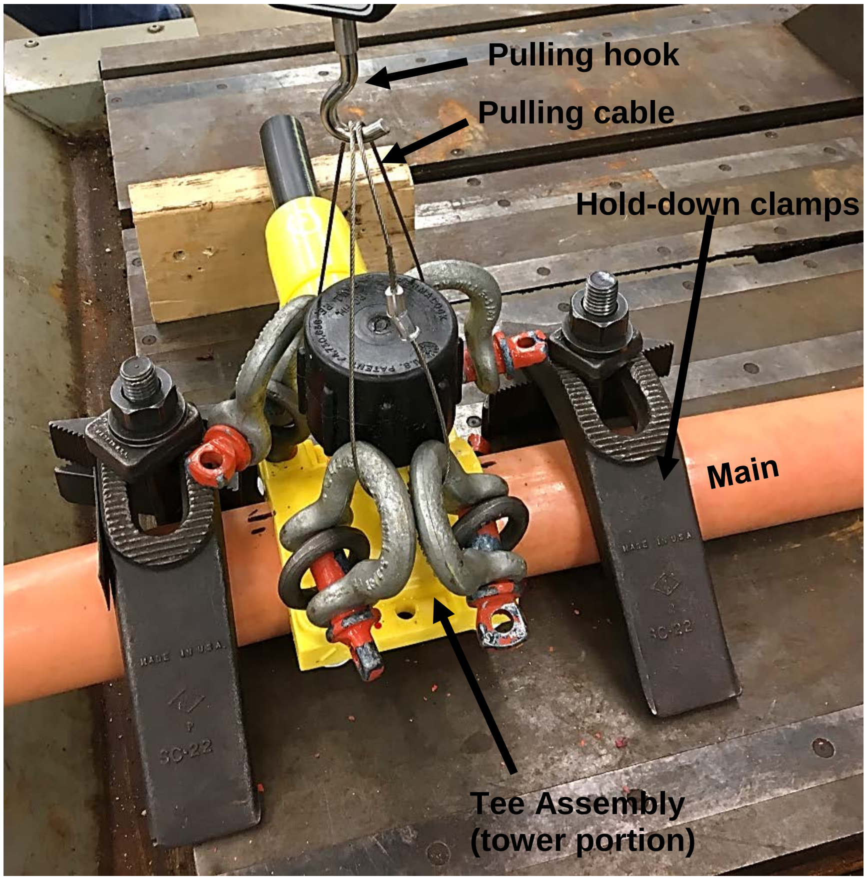


Figure 12. Laboratory set-up to intentionally separate the locking sleeve and tower from the main.

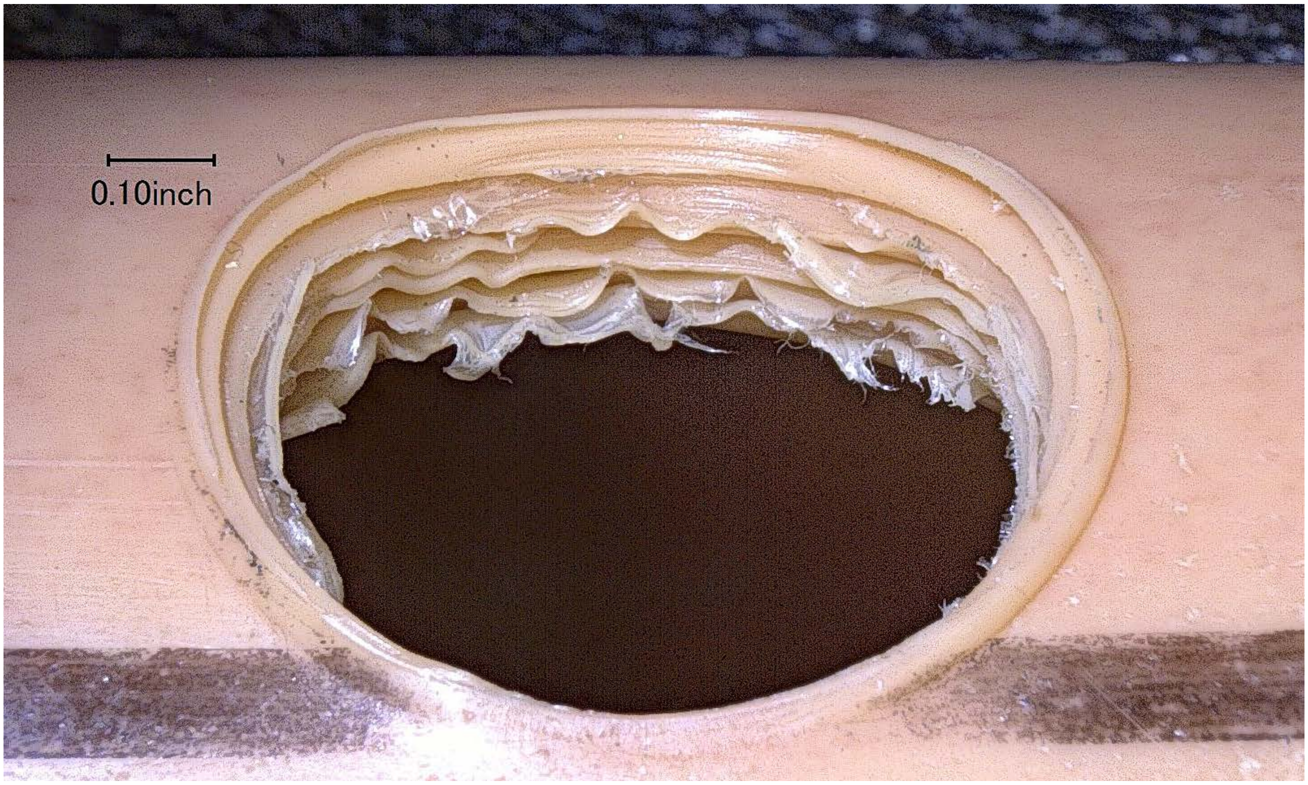


Figure 13. Photograph of the exposed outer top surface of the main after the locking sleeve and tower of tee assembly “C” was forcefully pulled out of the main showing thread damage in the pierced hole.

Figure 14. Photograph of the exposed inner surface of the main after the locking sleeve and tower of tee assembly “C” was forcefully pulled out of the main showing thread damage in the pierced hole.

APPENDIX A

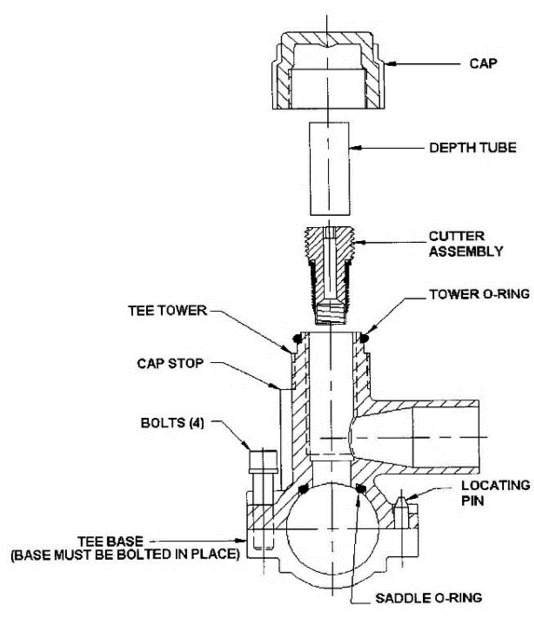
Perfection Permalock® Tee Assembly Manufacturer Installation Instructions

37575 Rev. F
Sht. 1 of 2

Perfection Installation Instructions

PERFECTION PERMALOCK® TEE
U.S. PATENT NOS. 4,730,636 & 4,809,735
U.K. PATENT NOS. 2199271 & 2234693

1. Remove TEE ASSEMBLY and DEPTH TUBE from the bag (check tee for TOWER and SADDLE O-RINGS).
2. Clean surface of main where TEE is to be installed. Avoid areas that are gouged or damaged. Lubricate SADDLE O-RING and main surface with leak test soap solution or silicone grease.
3. Bolt TEE onto PE main and tighten until the corners touch using a cross over tightening pattern (a gap between the flanges in the locating pin area is acceptable).
4. Connect service to the TEE TOWER outlet.
5. Test tee/service assembly in accordance with your company's standard leak test procedures.
6. Place DEPTH TUBE on top of the CUTTER ASSEMBLY. Thread CUTTER ASSEMBLY downward using a 5/16" hex wrench. Continue threading the CUTTER ASSEMBLY downward until it becomes snug. The DEPTH TUBE will be flush to 1/8" above the top of the TEE TOWER.
7. Thread CUTTER upward (counterclockwise) until top of CUTTER is flush with the top of the TOWER. This will gasify the service
   (Discard the DEPTH TUBE at this point).
8. Install CAP on the tower, hand tighten to CAP STOP.



Note: This product is designed to be installed by qualified installers. Qualification training manuals are available by writing or calling the Gas Sales Department of Perfection Corporation.

Perfection Corporation
A Subsidiary of American Meter Company
222 Lake Street
Madison, Ohio 44057-3189
Fax 440-428-7325
440-428-1171
www.perfectioncorp.com

APPENDIX A: This is the first page of the installation instructions for installing the Perfection Permalock® tee assembly to a main. The second page pertained to instructions for installing a mechanical coupling to service pipe (not attached).