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

July 16, 2020[1]

MATERIALS LABORATORY FACTUAL REPORT Report No. 18-067

A. ACCIDENT INFORMATION

Place	:	Dallas, Texas
Date	:	February 23, 2018
Vehicle	:	Pipeline operated by Atmos Energy
NTSB No.	:	PLD18FR002
Investigator	:	Sara Lyons[2]

B. COMPONENTS EXAMINED

Steel gas main that was installed behind the dwelling at 3539 Durango Drive and portion of the same gas main with a tee assembly that was installed behind the dwelling at 3524 Espanola Drive. The dwelling involved in the gas-fueled explosion was located at 3534 Espanola Drive.

C. DETAILS OF THE EXAMINATION

1. General Description

Figure 1 shows a photograph of the as-received 117.5-inch (10-foot) portion of the 2-inch diameter steel gas main that was installed behind the dwelling at 3539 Durango Drive. The gas main is located in an unpaved alley way. The gas main was installed in 1946 approximately four feet below the surface of the ground and is operated by Atmos Energy. The outer surface of the main was coated with a coal-tar enamel spiral wrap, with the outermost layer of the coating having a fine layer of Kraft paper. The maximum allowable operating pressure (MAOP) for the main was 55 pounds per square inch gauge (psig), and the main was cathodically protected against corrosion by consumable anodes.

Another segment of the same main with a tee assembly was cut on-site from an area located behind the dwelling at 3524 Espanola Drive, see figure 2. A polyethylene service pipe extended between the steel tee assembly and a meter riser for the dwelling at 3524 Espanola Drive. The length of the service pipe between the meter riser and tee assembly measured approximately 103 inches (8.6 feet). The base portion of the tee assembly was welded to the main. The tee assembly exhibited indications of a leak during an on-site leak test performed by Atmos Energy. The service pipe was cut on-site to facilitate transportation and handling. Visual examination at the NTSB Materials Laboratory of the service pipe, tee

[1] This laboratory report was originally completed on September 21, 2018 but later was revised based on minor comments received during the Technical Review, which was held on July 14, 2020.
[2] The on-site investigators were Ravi Chhatre and Roger Evans. The current investigator-in-charge is Sara Lyons.

assembly, and main in figure 2 showed no evidence of a crack. Appendix 1 shows a map of the dwellings relative to each other and approximate location of the excised main segments.

2. Safety Board Materials Laboratory Group Exam

The following individuals participated in the group examination of the pipe pieces between July 17 and 19, 2018 at the Safety Board's Materials Laboratory, Washington, D.C., and at NTSB Training Academy, Ashburn, Virginia:

Frank Zakar	NTSB	Senior Metallurgist
Roger Evans	NTSB	Investigator-in-Charge
Edward Komarnicki	NTSB	Engineering Technician
Aphrodite Strifas	NTSB	Student Intern
Alexandria Colletti	PHMSA	Accident Investigator
Jim Collins	Railroad Commission of Texas	Regional Manager
Paul Kurilecz	Atmos Energy	System Integrity Engineer

Examination of the pipe pieces continued after the group examination.

3. Steel Main Behind Dwelling 3539 Durango Drive

Visual examination of the as-received 10-foot gas main segment located behind dwelling 3539 Durango Drive revealed a circumferential crack on the top surface. The crack extended approximately halfway around the pipe circumference, in the area indicated in figures 3 and 4. The crack was located approximately 0.5 inches below the bottom surface of a 6-inch diameter polyvinylchloride (PVC) sanitary sewer pipe. The sewer pipe was oriented perpendicular to the length of the gas main. According to a representative from Dallas Water Utilities, the sewer pipe was built between 1995 and 1996. The sewer pipe was not submitted for examination. The outer face of the gas main was coated with a black tar enamel spiral wrap coating. The spiral coating was continuous and extended the length of the submitted main segment, with the exception of four isolated areas on the top side of the main indicated by brackets "A", "B", "C" and "D" in figure 1 where the coating had been damaged and was missing. The longitudinal length of the exposed areas of the main measured approximately 2 inches, 4 inches, 3 inches, and 2 inches, west to east, respectively. The exposed areas extended approximately halfway around the circumference of the main. The outer surface of the main in the area of the crack contained a depression relative to other areas, and this circumferential crack intersected the depression. Later in this report, the depression will be identified as a dent, see figure 5. The dent and crack were located approximately 68 inches from the west end of the as-received portion of the main. The exposed surface of the main in the four isolated areas was covered with a hard, compacted, adherent deposit. The deposit could not be removed with the scraping action of a wood tongue depressor. The coating outside of the four exposed areas was intact.

The gas main was gently rolled on the floor and a bow was noted along the length. A downward bow was noted below the general area of the crack. The bow deformation was located diametrically opposite the top portion of the main. With the crack facing down against the floor, a level was placed against the bottom of the main in the general area of the crack. This exercise disclosed an air gap between the bottom of the main and the ends of the level.

The gap between the main and the ends of the level measured approximately 0.3 inch and 0.1 inch, see Appendix 2. The maximum bow between the upper surface of the main and the floor was located in the general area of the crack and this vertical distance measured approximately 0.4 inch. Appendix 3 shows a photograph when the level was tilted to one side of the dent area. No evidence of a gap was noted on the side of the level in the area located away from the dent. When the level was placed on the bottom side of the main on other side of the dent, similar observations were noted (no gap in the area located away from the dent).

The hard deposit was removed from the surface of the main by placing a brass rod above the deposit and striking the rod with repeated blows from a hammer. This procedure removed the deposits from the surface and exposed several gouges. Each of the four exposed areas of the main contained at least one major gouge, see gouges between arrows “A1”, “B1”, “C1”, “C2”, and “D1” figures 6 through 12. The major gouges were oriented diagonal relative to the length of the main, with the exception that one major gouge, between arrows “C2” in figures 11 and 12, was nearly circumferential and intersected another major gouge, between arrows “C1” in figures 11 and 12. The major gouges contained evidence of metal flow deformation. Metal flow deformation on each major gouge was south to north, consistent with a gouge that was started on the south end of a gouge and ended at the north end.

Figure 13 shows the top surface of the main with an imaginary line extending along the length of the top dead center. The end of each gouge nearly intersected the top dead center of the main. The angle of each gouge was measured relative to the West end of the main along the top dead center when looking down at the main. The angle of each gouge relative to the length of the main was measured at the intersection between the longitudinal imaginary line at the top dead center of the main and an imaginary line that extended along the length of a gouge. The west end of the main at the top dead center was arbitrarily selected as zero degrees and measurements were made counterclockwise with respect to zero degrees. The measured angle was different for each gouge. Figure 13 shows the measured angle of each major gouge. The measured angle of the gouges ranged between approximately 35 degrees and 130 degrees relative to the west end of the main, when looking down.

As indicated earlier, each gouge contained evidence of metal flow deformation, with metal flow deformation toward the north end of each gouge, consistent with a gouge that started at the south end of each gouge. Figure 14 shows the measured longitudinal distance between the approximate starting point of each gouge. The longitudinal distance between the approximate starting point of each gouge ranged between 1 inch and 8.5 inches.

When visually inspecting the main, the cross section of each major gouge contained a round profile. Table 1 shows the measured length, width and depth of each major gouge. The length of the major gouges measured between 0.9 inch and 1.8 inches. The width of the gouges measured between 0.13 inch and 0.25 inch. The depth of each gouge measured roughly between approximately 0.007 inch and 0.018 inch. The areas next to each major gouge contained evidence of other minor gouges. The orientation of the minor gouges was different than that of a respective major gouge.

3.1 Exposing the Mating Fracture Faces

A circumferential saw cut was made approximately 3 inches on each side of the crack, resulting in a cut ring portion of the main. A longitudinal saw cut was made through the excised ring portion of the main that nearly intersected the ends of the crack. In order to expose the mating faces of the crack, one end of the ring portion of the main was held by a table vise and the other end was held by pliers. The pliers were used to force open the crack to expose the mating faces of the fracture. Figure 15 shows a photograph of the west face of the exposed fracture.

Both halves of the ring portion were re-assembled to appear as if intact. The ring portion with the west face of the fracture was placed against the cut end of the non-deformed main. The depth of the dent was measured relative to the top surface of the non-deformed cut end of the main. The vertical distance between the top surface of the dent and the top surface of the non-deformed pipe was measured with the needle end of a caliper. The depth of the dent measured approximately 0.46 inch. The diameter of the dent when looking down at the dent with the mating halves of the fracture faces placed next to each other measured approximately 1.4 inch.

3.2. Bench Binocular Microscope Examination

Bench binocular microscope examination of the west face of the fracture revealed ratchet marks indicative of a crack with multiple origins emanated from a dent at the outer surface, see figures 15 through 16. The face of the fracture for the most part was covered with brown oxide. The fracture face at the outer surface in several isolated areas of the dent contained evidence of minor shear lips, whereas, the inner surface in the area below the dent contained evidence of one major shear lip, see figure 16. The fracture face on the inner surface also contained evidence of minor shear lips on both sides of the major shear lip. The fracture propagated down and to each side of the dent. Fracture propagation was approximately through half of pipe circumference and terminated in the areas indicated by solid lines in figure 15. The fracture face outside of the dashed line in figure 15 was the laboratory induced fracture.

The west face of the fracture was cleaned with cellulose acetate replica tape. A strip of replica tape was immersed in acetone and when it became soft was placed over the fracture face. Another layer of replica tape that was soaked in acetone and was placed on top of the previous replica tape layer, to provide backing support for the first applied replica tape layer. When hardened the double layer replica tape was peeled from the fracture face and this procedure removed deposits from the fracture face. The replica tape cleaning procedure was repeated four times. The fracture face near the ends of the crack at the inner and outer edges contained evidence of a minor river (chevron) pattern that pointed back to the dent, consistent with a crack that propagated away from the dent.

The greatest reduction in wall thickness along the fracture face was located in the area of the dent. The wall thickness in the area of the dent measured approximately 0.12 inch, whereas, in non-deformed areas measured approximately 0.15 inch, calculates to a wall reduction of 20%. The wall thickness was measured with a point micrometer.

3.3 Scanning Electron Microscope (SEM) Examination

SEM examination of the west face of the fracture revealed cleavage fracture features that extended the entire length of the crack. The cleavage features showed evidence of pitting. The pitting was less severe near the ends of the crack, see figure 17. The pitted cleavage fracture features were observed on isolated portions of the fracture face prior to replica tape cleaning procedure. The fracture produced in the laboratory, located outside (below) the black lines in figure 15, contained several bands of cleavage fracture features that were separated by micro-void coalescence fracture features, with the end of the laboratory fracture face having evidence of micro-void coalescence fracture features typical of ductile overstress separation. Figure 18 shows a transition region between a cleavage fracture feature and micro-void coalescence fracture feature.

4. Pressure Testing

Prior to detailed visual examination, pressure testing was conducted by the NTSB Materials Laboratory on the as-received parts to determine whether air was leaking (flowing) out of the submitted part, the amount of pressurized air that was leaking, and its location. Pressure was supplied by a shop compressor. The pressure and rate of air leak was measured with the VPFlowScope® in-line electronic flow meter, manufactured by Van Putten Instruments, Netherlands. Pressure testing was conducted up to MAOP of 55 psig, at 10 psig intervals, with the exception that the last pressure increase was at a 5 psig interval. The flow rate was measured after holding pressure for approximately 3 minutes.

4.1 Main with a Dent and Circumferential Crack

The 10-foot segment of the main with the circumferential crack was pressure tested. The cut end was plugged by the NTSB with a mechanical pipe plug that contained a pass-through port that allowed pressurized air to enter the main. The other end contained a weld plug, as indicated earlier. The measured pressure and flow rates are shown in table 2. The volumetric leak rate for air was converted to volumetric leak rate for natural gas. The converted values are shown in table 2. The specific weight of natural gas is dependent on the composition of the natural gas and can vary in the range between 0.554 and 0.87. For the purpose of this report, the specific weight value of 0.59 was used for converting volumetric leak rate in air to volumetric leak rate for natural gas.

An attempt was made to pressurize the pipe to 55 psig, MAOP of the pipe, but this was not possible because air flowing out of the crack exceeded the capacity of the air compressor to provide the desired pressure. The pressure test was terminated at 33 psig. A plot of the pressure and flow rate are shown below table 2. A linear line was drawn through the plotted points to roughly extrapolate the value of the flow rate if the pressure was supplied at 55 psig. At 55 psig, the flow rate was estimated to be approximately 12.7 cubic feet per minute (CFM) for air which converted to a flow rate of approximately 16.5 CFM for natural gas. The tables also show the converted flow rate in cubic feet per hour (CFH).

4.2 Gas Main with Tee Assembly Located Behind Dwelling 3524 Espanola Drive

A 3-feet segment of the steel main with a steel tee assembly and polyethylene service pipe located behind dwelling 3524 Espanola Drive was submitted for examination. Pressure testing was conducted on the portion of the service pipe that contained the riser, and separately on the portion of the service pipe that contained the tee assembly and main, since the service pipe was severed to facilitate transportation.

4.2.1 Service Pipe Containing the Tee Assembly and Main

As indicated earlier, a tee assembly was installed between the service pipe and main. Both ends of the main were plugged with mechanical plug and the cut end of the service pipe was attached to a mechanical plug containing a pass-through port that allowed pressurized air to enter the service pipe, tee assembly and main. The measured pressure and flow rates are shown in table 3. The volumetric leak rate for air was converted to volumetric leak rate for natural gas, and the converted values are shown in table 3. At 55 psig the meter showed a flow rate of approximately 0.2 CFM, with no evidence of air flow below this 55 psig value. A soap solution was sprayed on various parts of the tee assembly, main, and service pipe, during all phases of the pressure testing. Areas that show evidence of bubbles are a positive indication of a leak. The tee assembly showed evidence of bubbles only when the pressure reached 55 psig. Soap bubbles were noted in the area below the cap and at the base of the tee assembly, evidence that there was a leak at these two locations of the tee assembly, see figures 19 and 20.

4.2.2 Service Pipe Segment Containing the Meter Riser

The cut end of the as-received service pipe was attached to a mechanical plug containing a pass-through port that allowed pressurized air to enter the service pipe. The upper end of the meter riser contained a plug that was installed on-site. The measured pressure and corresponding flow rates are shown in table 4. The service pipe was subjected to 56 psig and showed zero air flow. A soap solution was sprayed on various parts of the service pipe and meter riser. Areas that show evidence of bubbles are a positive indication of a leak. The service pipe and meter riser showed no evidence of bubbles, indication of no evidence of a leak, see figure 21.

Prepared by:

Frank Zakar
Senior Metallurgist

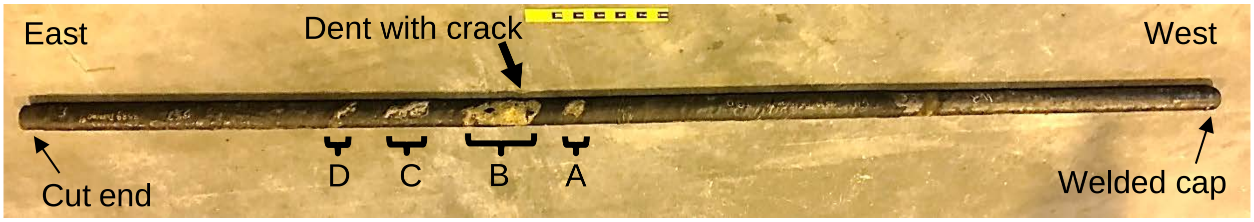


Figure 1. As-received 10-foot segment of the main that was located behind dwelling 3539 Durango Drive showing the top surface and a dent with a circumferential crack. Exposed areas of the main with damaged coating are indicated by brackets “A”, “B”, “C”, and “D”.

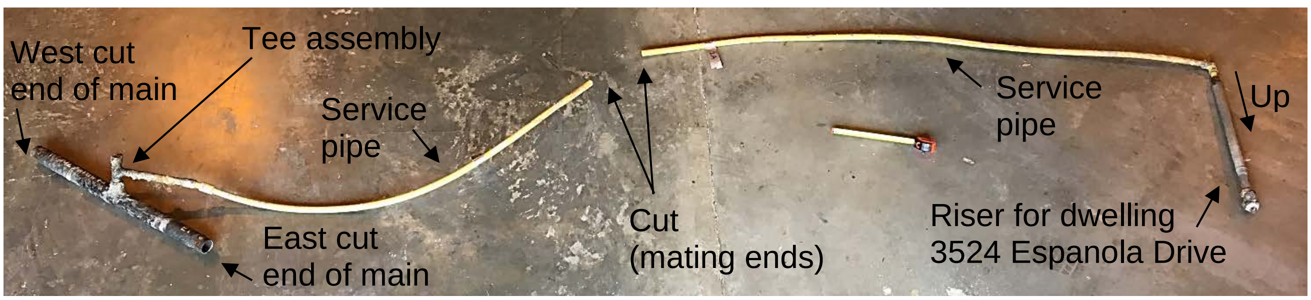


Figure 2. As-received riser and service pipe for dwelling 3524 Espanola Drive that connects to the tee assembly and main.

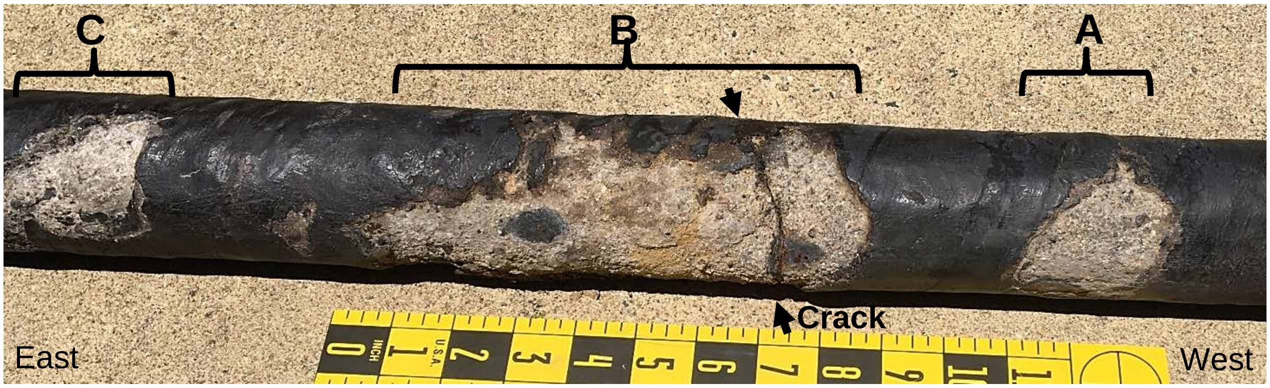


Figure 3. Close-up photograph of the top portion of the as-received main, showing exposed areas of the main with damaged coating, and dent with crack. The crack intersected the dent.

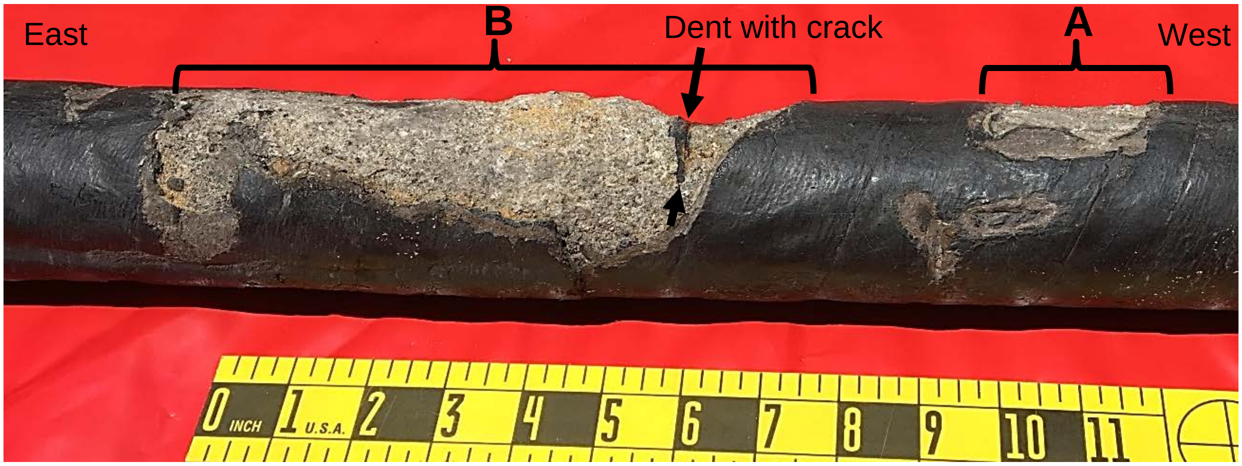


Figure 4. Side view of the as-received main showing the dent with a crack, in the region indicated by bracket "B" in figure 1. The crack intersected the dent.

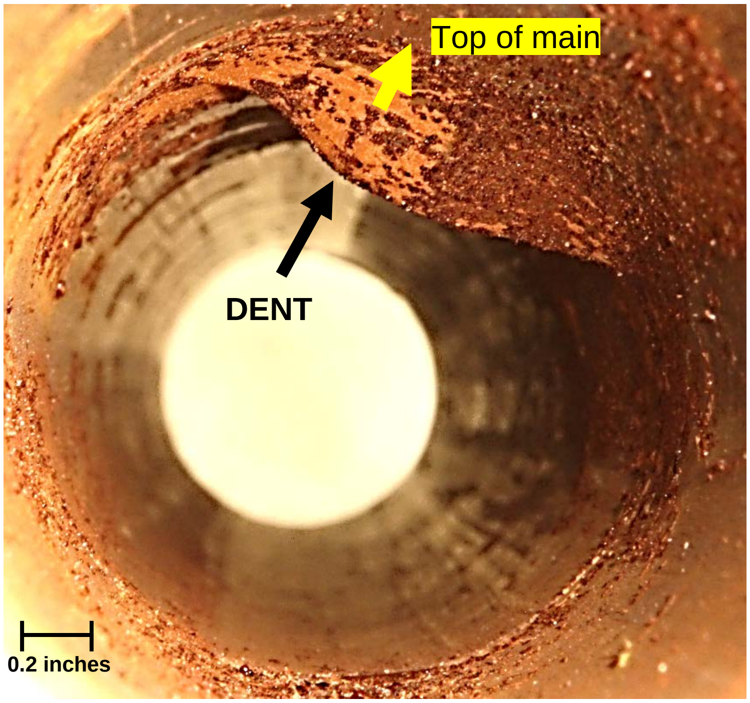


Figure 5. View of the inner surface of the main looking east showing a dent that intersected the circumferential crack. Arrow also points to the approximate top of the main.

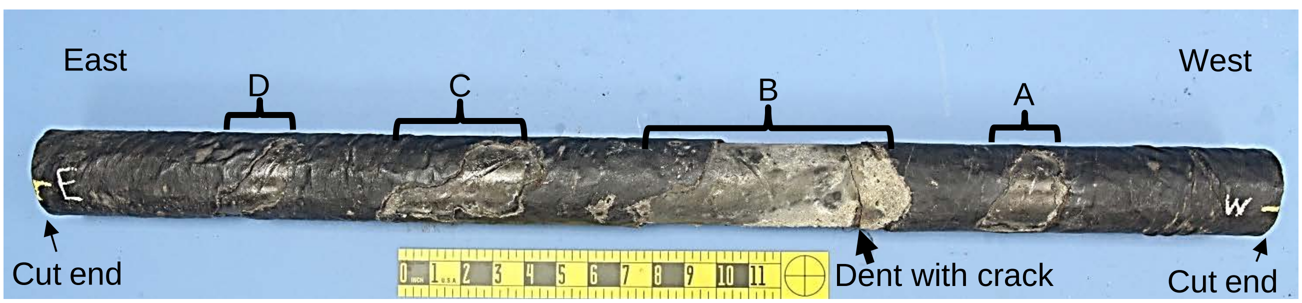


Figure 6. Top surface of the main showing areas where the coating was damaged, indicated by brackets “A”, “B”, “C”, and “D”, and dent with a crack, shown after removing hard deposit from exposed surfaces. The horizontal line next to the “East” and “West” position mark the top of the main.

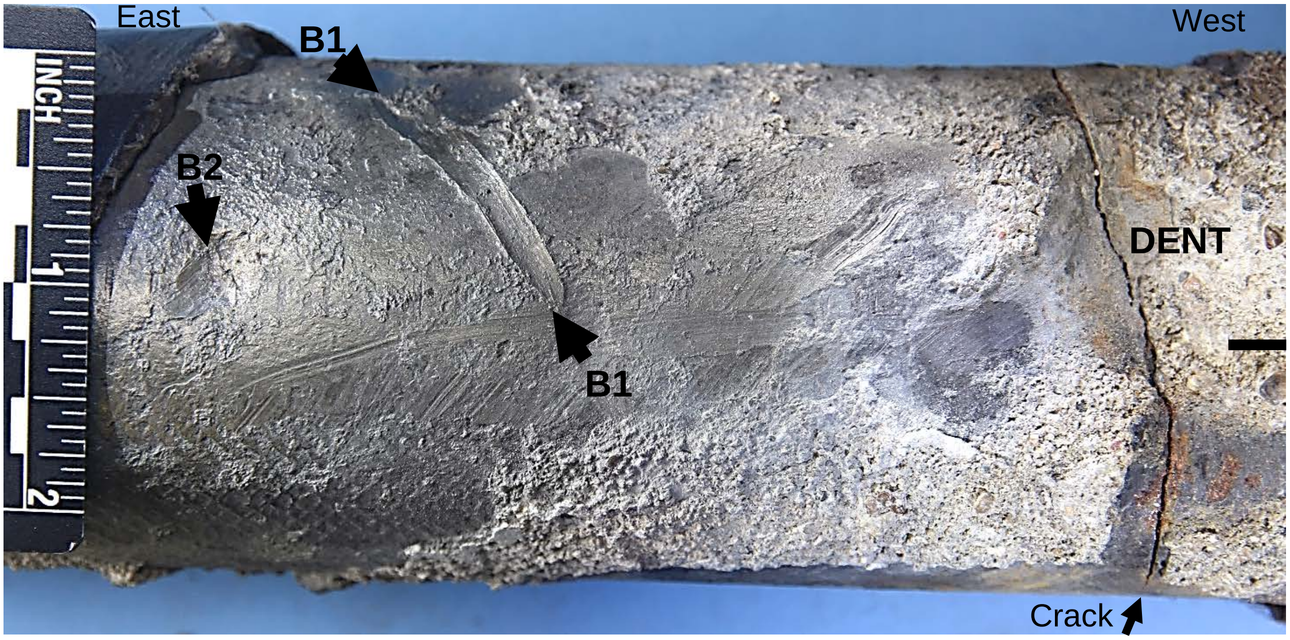


Figure 7. Close-up photograph of the top side of the main in region “B” in figure 6 showing the crack and dent, after removing hard deposit from the surface in areas outside of the dent and exposing a gouge between arrows “B1”. A smaller dent, approximately 0.25-inch diameter, was found in the area indicated by arrow “B2”. The exposed surface contained evidence of other gouges. The short black line on the side edge of this figure and those in figures 9, 10 and 11 indicate approximate top of the main.

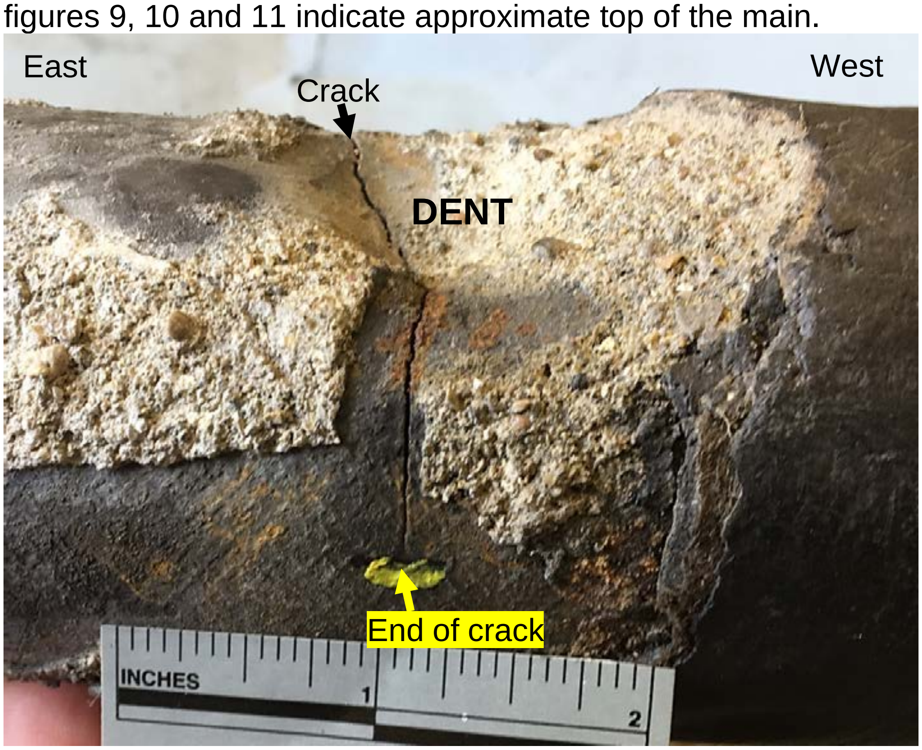


Figure 8. Close-up photograph of the side view of the main showing a crack that intersected the dent, region “B in figure 6. In this figure deposits were removed from the areas outside of the dent.

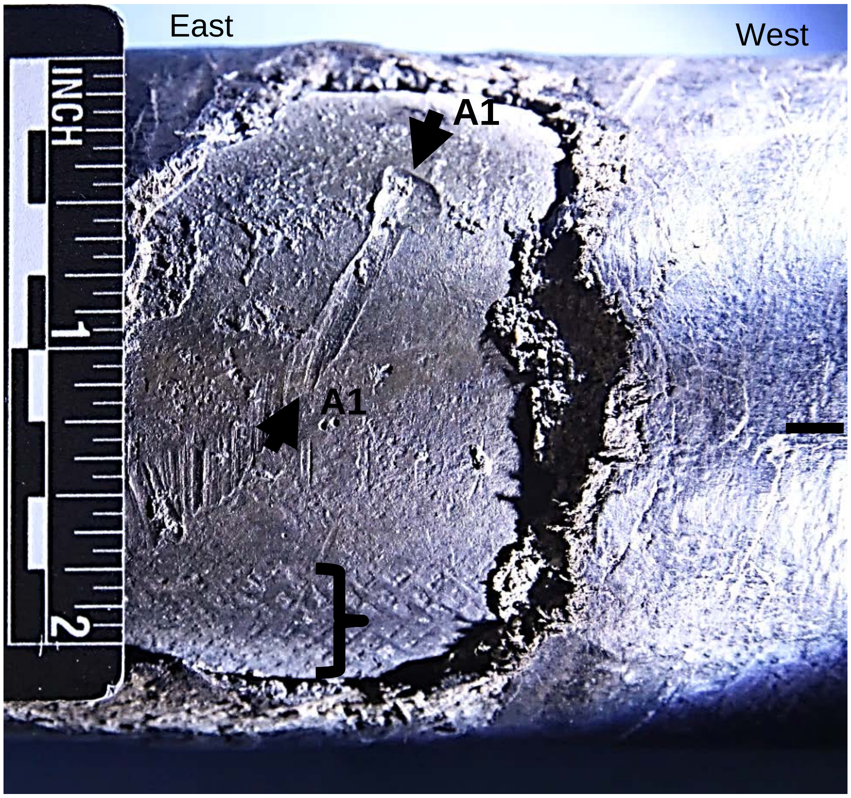


Figure 9. Close-up photograph of the top side of the main in region “A” in figure 6 showing the gouge between arrows “A1”, after removing hard deposit from the surface. The length of the main on the outer surface contained a crisscross mechanical pattern between the 9 and 11 o’clock position and the 3 and 5 o’clock position, looking east, such as in area indicated by a bracket, where 12 o’clock is the top of the main.

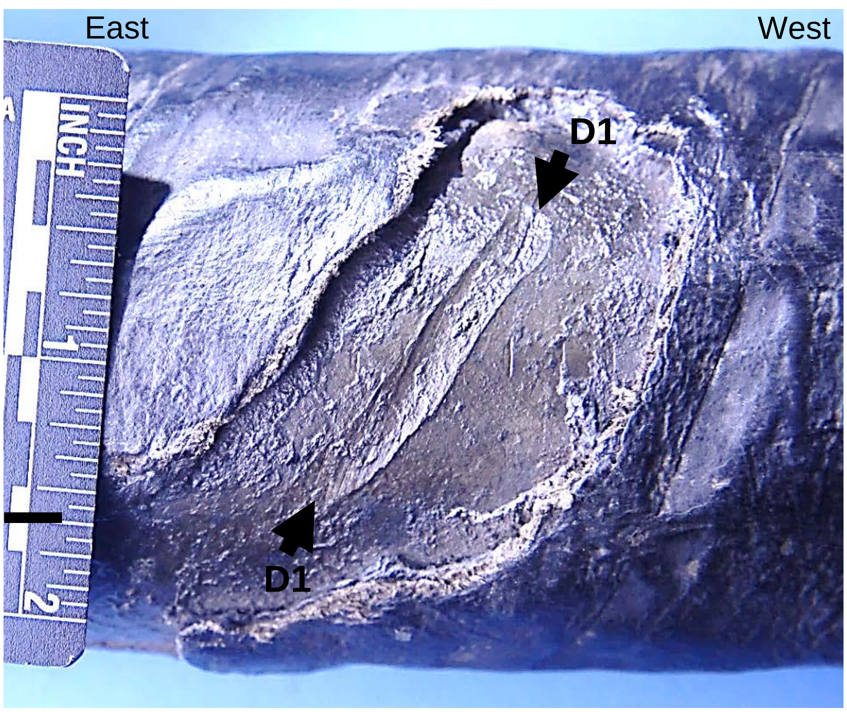


Figure 10. Close-up photograph of the top side of the main in region “D” in figure 6 showing the gouge between arrows “D1”, after removing hard deposit from surface.

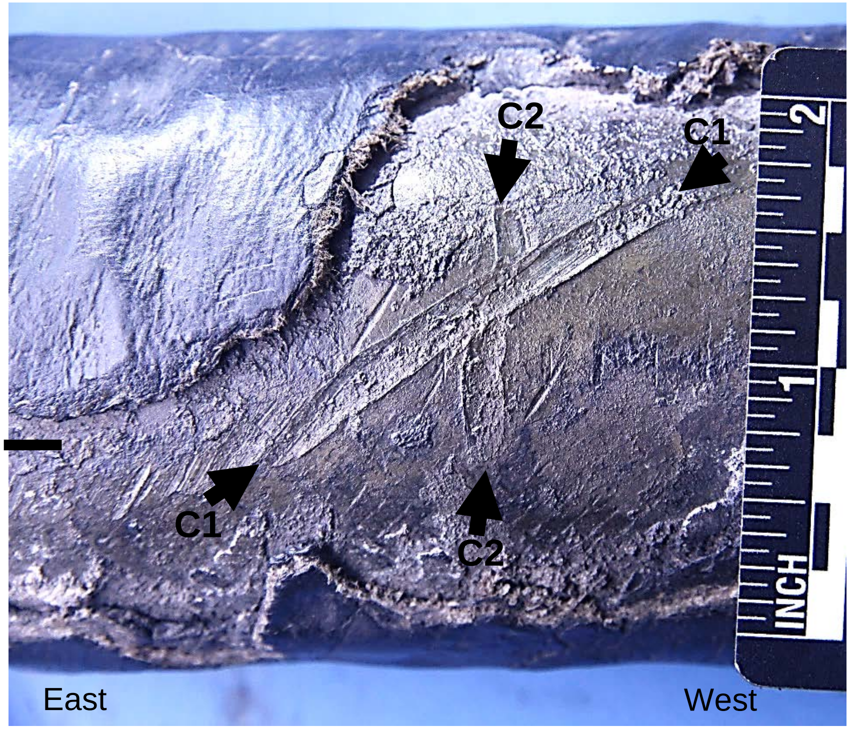


Figure 11. Close-up photograph of the top side of the main in region “C” in figure 6 showing the gouge between arrows “C1”, after removing hard deposit from the surface. This gouge had intersected another gouge between arrows “C2”.

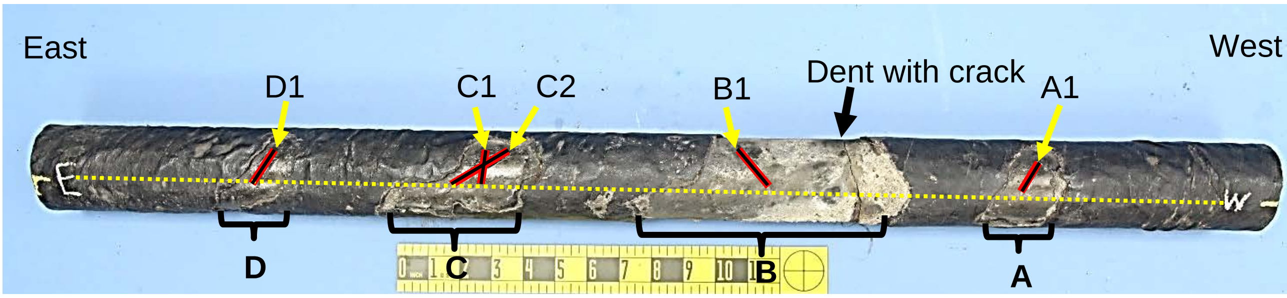


Figure 12. Top surface of the main showing location of five major gouges, “A1”, “B1”, C1”, “C2”, and “D1”, indicated by black and red outlines (black and red outlines are not to scale). Top of main line is indicated by a yellow dashed line.

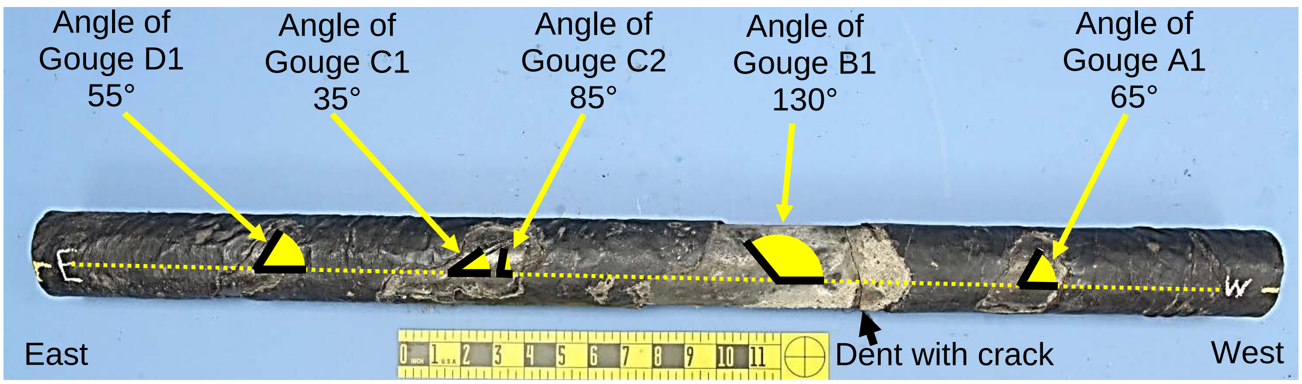


Figure 13. Top surface of the main showing the measured angle of major gouges “A1”, “B1”, “C1”, “C2”, and “D1”. The angle was measured at the intersection between an imaginary line that was drawn through a gouge and an imaginary line that was drawn through the top of main (yellow dashed line). West was arbitrarily referred as zero degrees and each angle was measured counterclockwise relative to zero degrees when looking down.

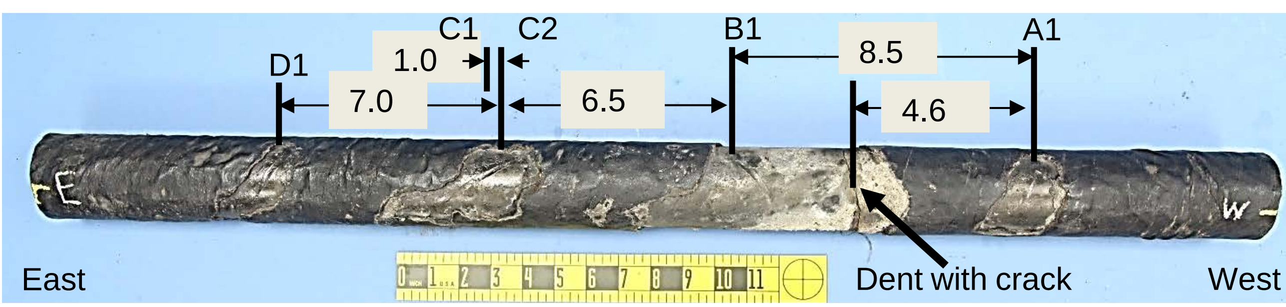


Figure 14. Top surface of main showing measured distance in inches between the initial (start) position of gouges “A1”, “B1”, “C1”, “C2”, and “D1” relative to each other and the dent with a crack.

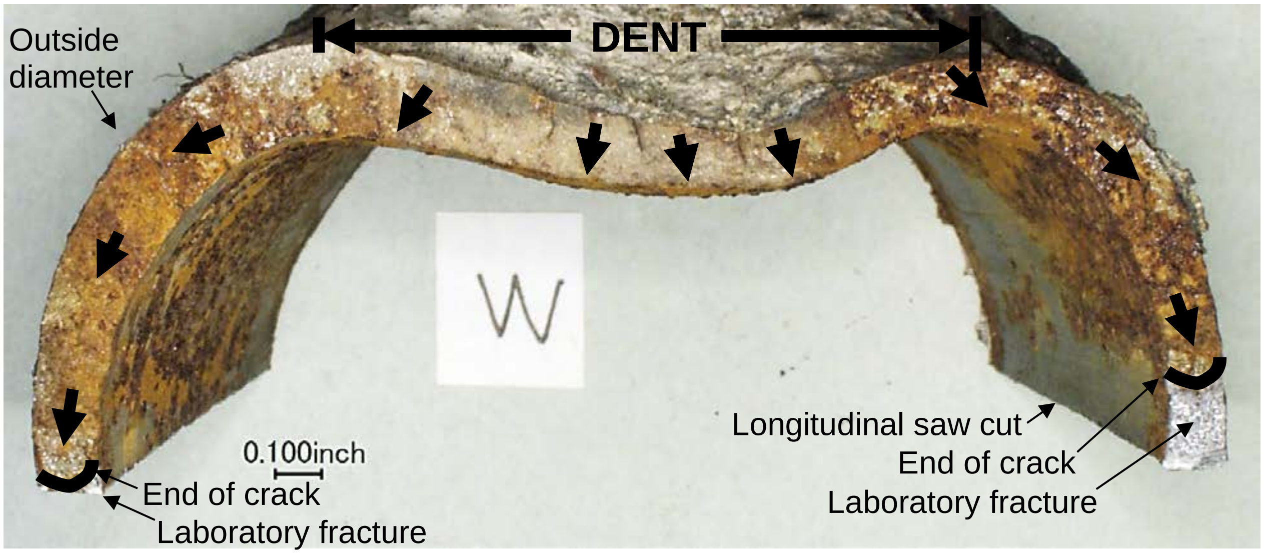


Figure 15. West face of the fracture after separating the mating faces of the circumferential crack.

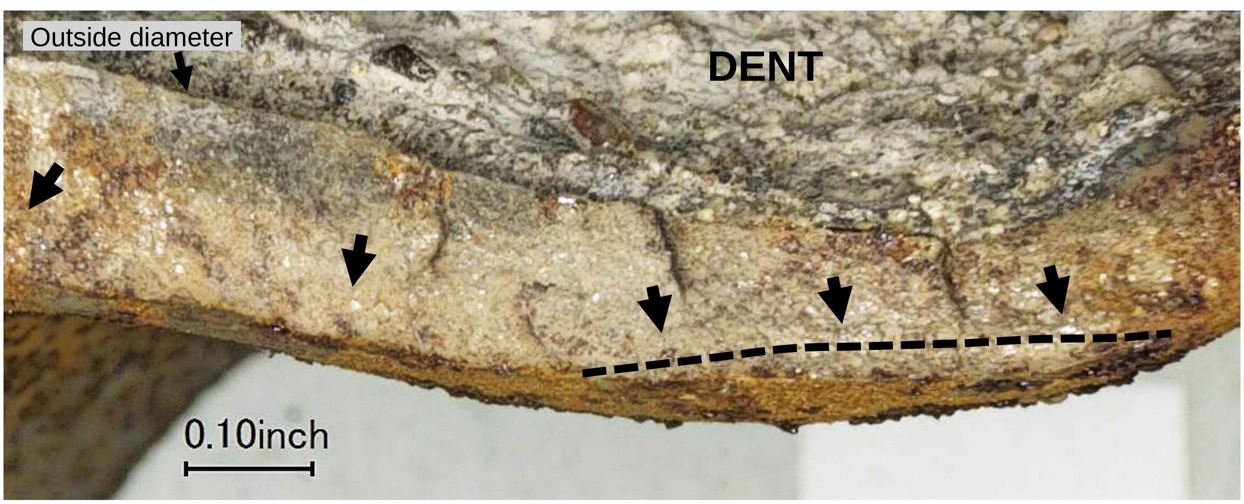


Figure 16. Close-up photograph of the west face of the fracture showing the bottom portion of the dent. A major shear lip was found on the inner surface in the area indicated by a dashed line. Minor shear lips were noted on the inner surface of the dent and on the outer surface in areas outside of the major dent (not readily visible at this magnification).

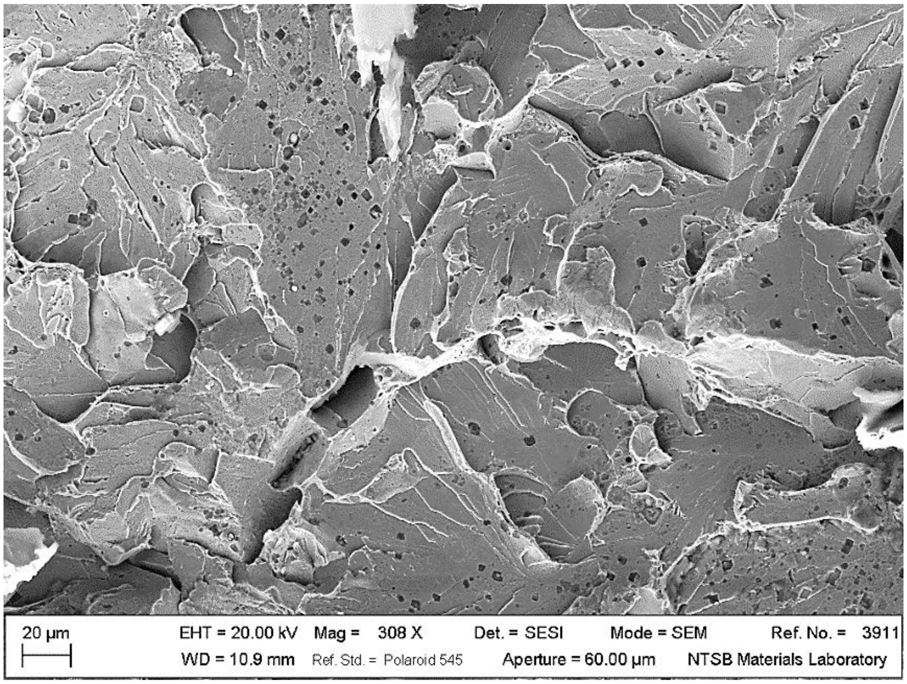


Figure 17. SEM image of cleavage fracture features in the portion of the crack near the dent. The fracture features contained evidence of pitting.

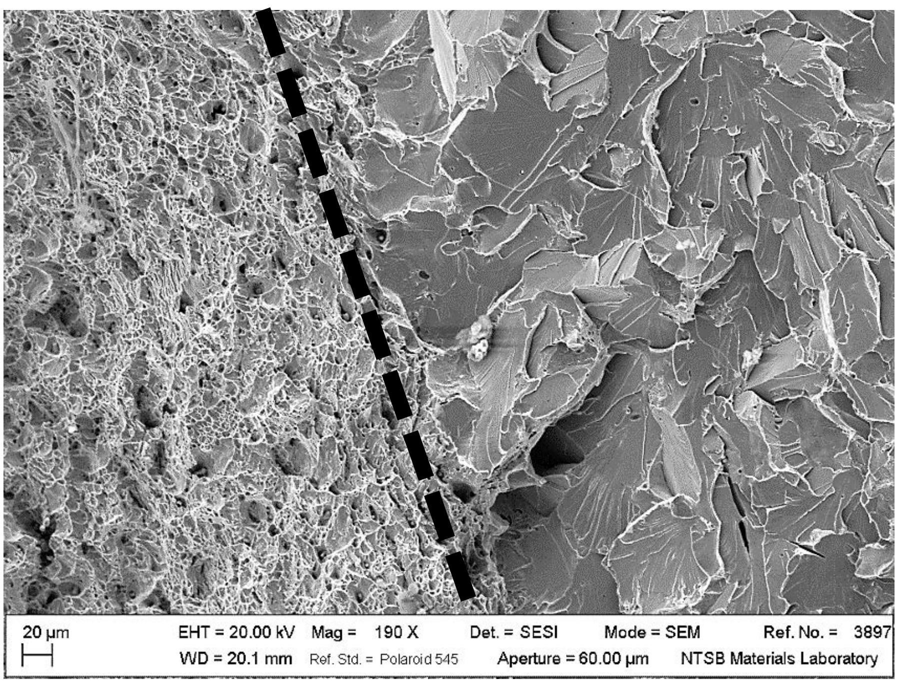


Figure 18. SEM image of the fracture at the border indicated by a dashed line between the terminus of the crack (cleavage features on the right) and laboratory induced fracture portion (micro-void coalescence fracture features on the left).

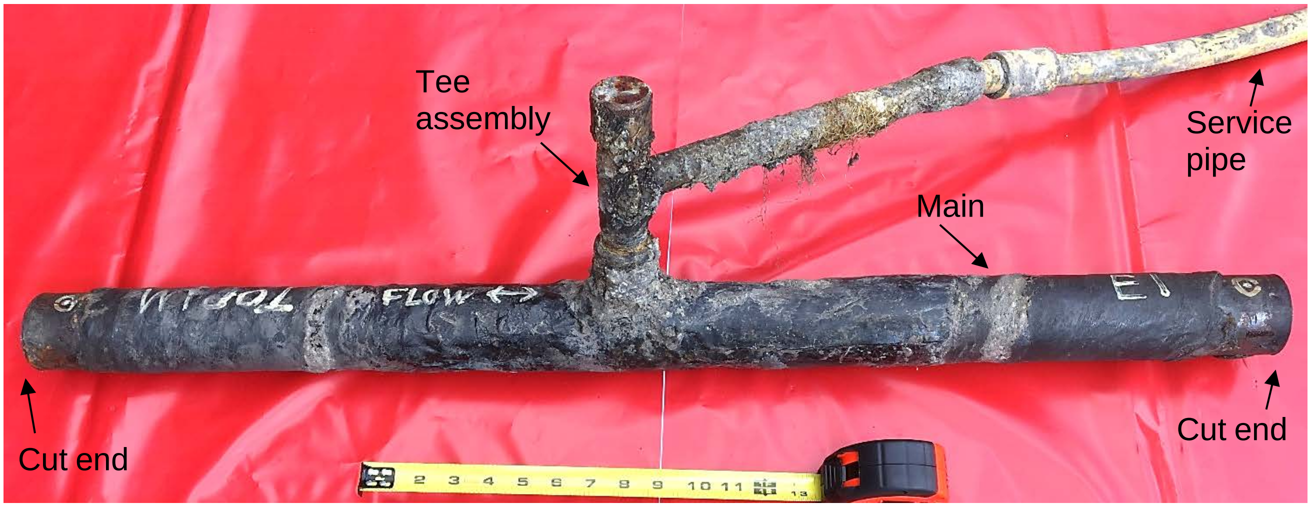


Figure 19. Close-up view of the Tee assembly and as-received portion of the main with the service pipe

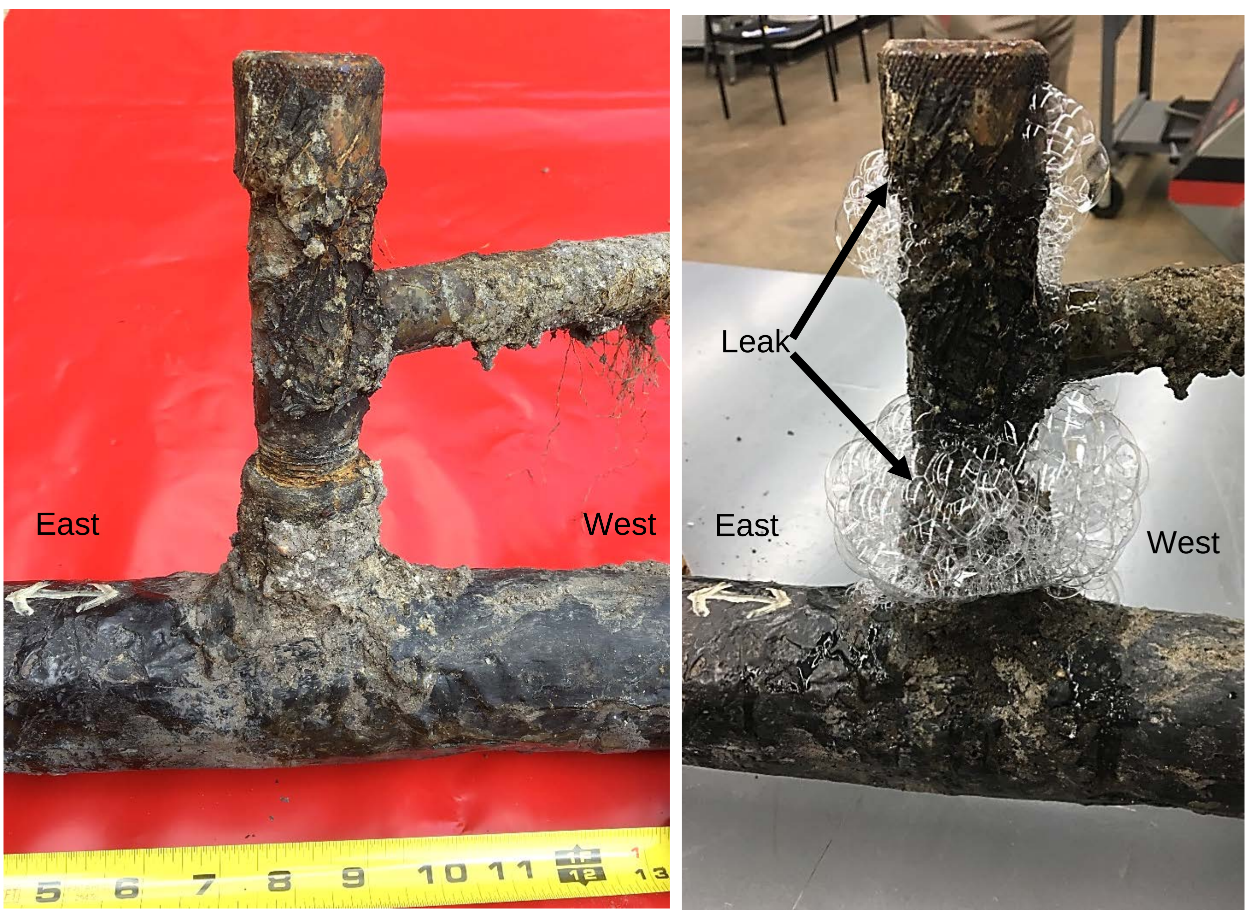


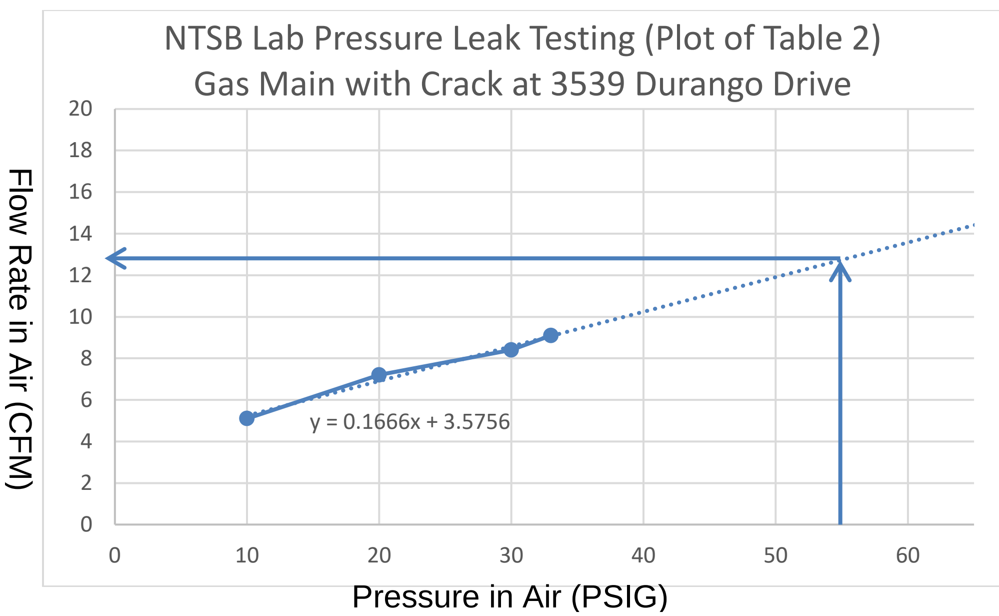
Figure 20. Side view of the tee assembly in the as-received condition (left) and when exposed to soap solution during pressure leak testing at NTSB showing soap bubbles emanating from an area below the cap and from the threaded joint at the base of the tee assembly indicating a leak (right).

Figure 21. Close-up photograph of the as-received gas meter riser and portion of the service pipe.

Table 1 Size of Gouges found on Gas Main at 3539 Durango Drive (inches)			
Gouge	Length	Width	Depth
A1	0.9	0.13	0.008
B1	1.2	0.13	0.018
C1	1.8	0.19	0.010
C2	0.9	0.19	0.007
D1	1.4	0.25	0.013

Table 2 Pressure Leak Testing at 80°F of the Gas Main at 3539 Durango Drive				
Applied Air Pressure (PSIG)	Measured Volumetric Leak Rate in Air		Calculated Volumetric Leak Rate For Natural Gas	
	(CFM)	(CFH)	(CFM)	(CFH)
10	5.1	306	6.6	398
20	7.2	432	9.4	562
30	8.4	504	11.0	655
33	9.1	546	11.8	710
55	[12.7]	762	16.5	991

Note: Leak rate in air at [12.7 CFM] was extrapolated from plotted data, see below.

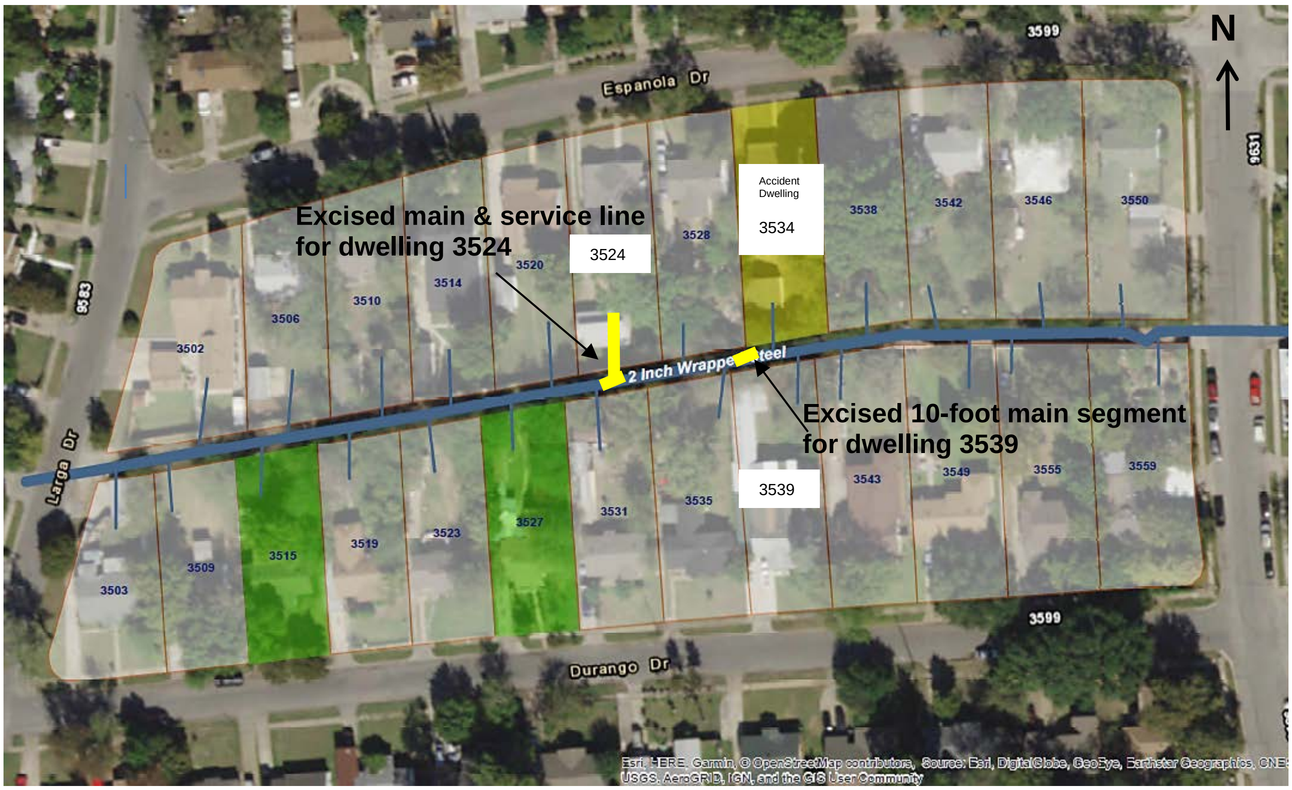


Plot of pressure vs. flow rate in air from measured values in table 2. Dashed line represents a linear line that was extrapolated from the plotted data. At 55 PSIG, which is the MAOP, the flow rate in air would be approximately 12.7 CFM, which converts to approximately 16.5 CFM for natural gas.

Table 3 Pressure Leak Testing at 73°F of the Tee assembly at 3524 Espanola Drive				
Applied Air Pressure (PSIG)	Measured Volumetric Leak Rate in Air		Calculated Volumetric Leak Rate For Natural Gas	
	(CFM)	(CFH)	(CFM)	(CFH)
13.1	0	0	0	0
20.0	0	0	0	0
30.4	0	0	0	0
40.2	0	0	0	0
55.0	0.2	12	0.3	16

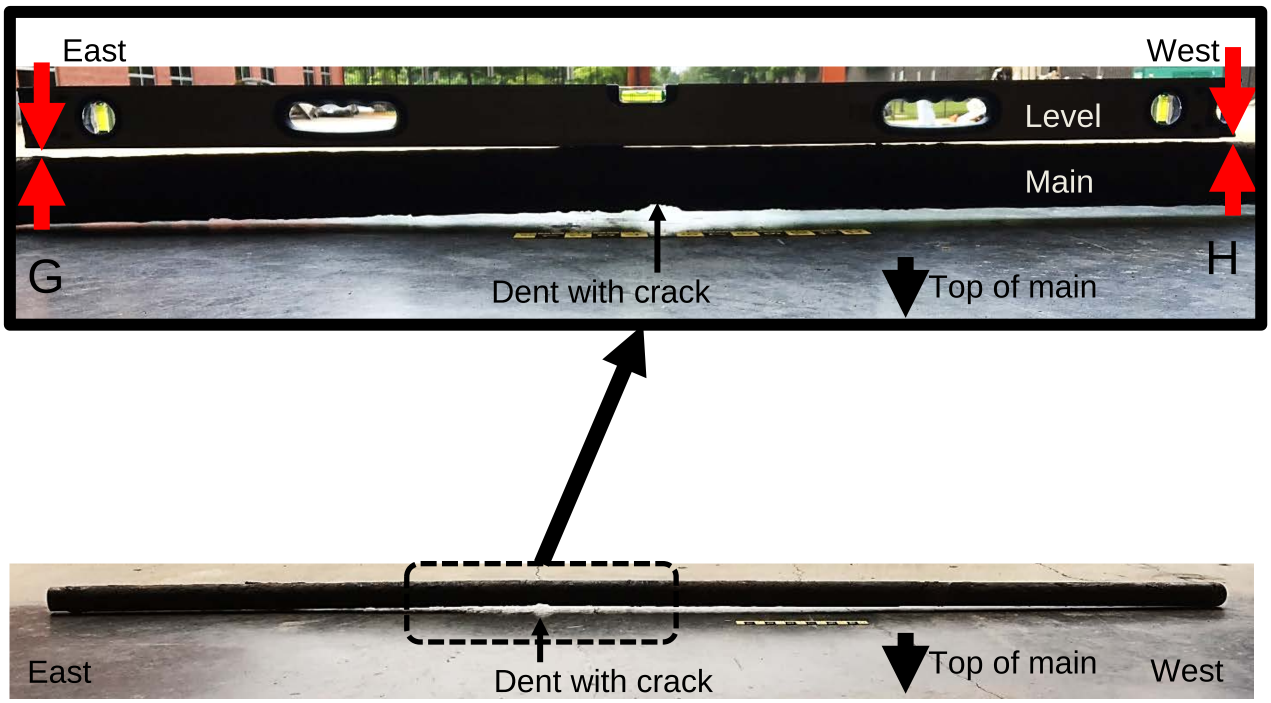
Table 4 Pressure Leak Testing at 73°F of the Gas Riser at 3524 Espanola Drive				
Applied Air Pressure (PSIG)	Measured Volumetric Leak Rate in Air		Calculated Volumetric Leak Rate For Natural Gas	
	(CFM)	(CFH)	(CFM)	(CFH)
9.0	0	0	0	0
20.4	0	0	0	0
30.3	0	0	0	0
40.4	0	0	0	0
56.0	0	0	0	0

APPENDICES

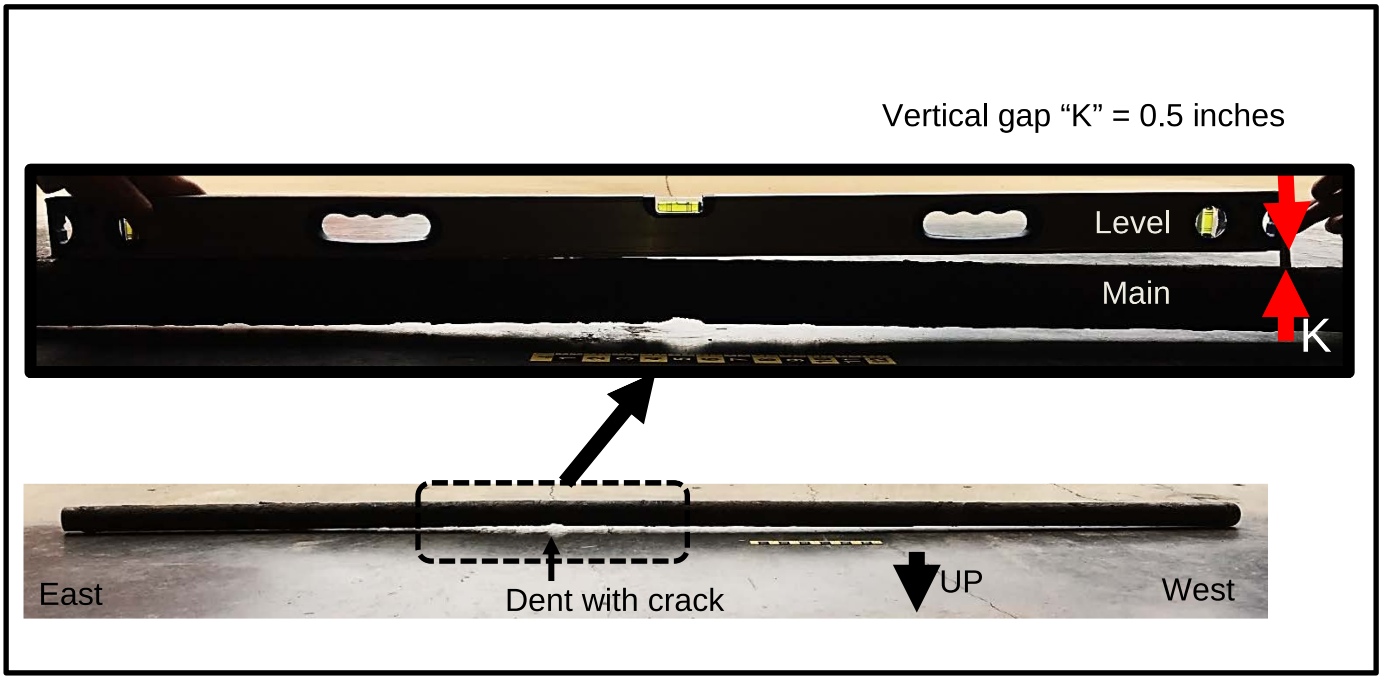


Appendix 1. Map showing the location of the excised pipe segments and respective house (dwelling) numbers. Yellow lines represent location of the excised main and service segments. A 10-foot segment of the main was excised from the ground behind 3539 Durango Drive. Another segment of the same main was excised from the ground behind 3524 Espanola Drive that includes the tee assembly, service pipe, and gas riser to the house. Blue line represents the 2-inch diameter main located behind the dwellings and associated service lines.

Vertical gap “G” = 0.3 inches
Vertical gap “H” = 0.1 inches
Length of level was 3.5 feet
Vertical gap between floor and upper surface of main = 0.4 inches



Appendix 2. Bottom photograph shows the side profile of the as-received 10-foot segment of the main with the dent and crack facing down to the ground. Top photograph shows a close-up view of the main in the area of the crack. A level was placed at the bottom portion of the main to show evidence of downward deformation in the area of the crack (top photograph). The greatest vertical deformation was located in the general area of the crack. Measured values are shown above the photograph.



Appendix 3. Side view of the main (lower side of page) and a level that was resting at the bottom side of the main on one side of the dent (upper side of page).