NBSIR 80-1985R

Examination of Failed Eight Inch Diameter Cast Iron Pipe Natural Gas Main, Philadelphia, Pennsylvania

T. Robert Shives

Fracture and Deformation Division
Center for Materials Science
National Measurement Laboratory
National Bureau of Standards
Washington, D.C. 20234

September 1979

Issued February 1980

Failure Analysis Report

Prepared for

**National Transportation Safety Board
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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*

Luther H. Hodges, Jr., *Deputy Secretary*
Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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SUMMARY

At the request of the National Transportation Safety Board, the National Bureau of Standards performed an examination of a fractured eight inch diameter cast iron pipe natural gas main. An explosion and fire at the location of the failure had occurred on May 13, 1979 at Tacony and Margaret Streets in Philadelphia, Pennsylvania. The supporting soil beneath the pipe was missing at the location of the failure. The pipeline had completely fractured circumferentially in three places, and after fracturing, fell into the cavity created by the missing soil. Failure appeared to be due to the application of a bending load to the unsupported pipe.

The non-uniform wall thickness indicated that the pipe was pit cast and therefore was probably rather old. Today, such pipe is normally centrifugally cast which results in a uniform wall thickness.

Only one of the fracture surfaces was selected by the National Transportation Safety Board for examination by the National Bureau of Standards. Corrosion product on that fracture surface was rather easily removed, indicating that the fracture was likely recent. Cleavage was the predominant fracture mode. The amount of graphitization at the fracture was not considered excessive.

The hardness of the material was typical for gray cast iron. The chemical composition was typical for this material, but the phosphorus content was higher than desirable according to today's practices. The microstructure appeared to be satisfactory with the possible exception of more steadite (iron-iron phosphide eutectic) than desirable according to today's practices.

Examination of Failed Eight Inch Diameter Cast Iron Pipe Natural Gas Main, Philadelphia, Pennsylvania

1. INTRODUCTION

1.1 Reference

National Transportation Safety Board, Washington, D.C. 20594. This investigation was conducted at the request of Mr. Jerry A. Houck, Metallurgist, National Transportation Safety Board. The requesting letter was dated June 25, 1979.

1.2 Background Information

Information in this section was furnished by the National Transportation Safety Board and by representatives of the Philadelphia Gas Works. On May 13, 1979, there was an explosion and fire at Tacony and Margaret Streets in Philadelphia, Pennsylvania. The explosion and fire were attributed to the ignition of an accumulation of natural gas at the site.

After the explosion and fire, the eight inch diameter natural gas main pipe at this location was found to be completely fractured circumferentially in three places. Two of these fractures were in an 11 foot length of pipe, and the other was in a 16 foot, 9 inch length of pipe. There was another 16 foot, 9 inch length of pipe between the two lengths containing the fractures.

The pipeline was under the paving of Margaret Street and had been buried to a depth of 3 feet, 3 inches (measured from the top of the pipe).

When the pipeline in the region of the fracture was uncovered, the soil beneath the pipeline was missing to a depth ranging from 3 inches to about 3 feet, 9 inches below the level where the pipeline had originally been installed. This missing soil created a cavity and left the pipeline unsupported. When the pipe fractured, it fell into this cavity.

A fractured six inch diameter cast iron water main was in close proximity to the fractured gas pipe.

1.3 Parts Submitted

A small piece of the eight inch diameter gas pipe was submitted to NBS for examination. This piece varied in length from about 3 inches to 4 1/4 inches around the circumference and contained one of the fracture surfaces from the fracture in the 16 foot, 9 inch length. This piece is shown as received at NBS in figure 1. The other fracture surfaces were not submitted by the National Transportation Safety Board.

In addition, three two-foot pieces of pipe, one from each of the two pipe lengths that had fractured and one from the 16 foot, 9 inch length between the two lengths containing the fractures, were submitted. These pieces did not contain a fracture surface. The pieces are shown as received at NBS in figures 2, 3, and 4 and were identified respectively as from west end of 16 foot, 9 inch section, from 11 foot section, and from east end of 16 foot, 9 inch section. The submitted fracture was from the same length of pipe from which the two-foot piece identified as being from the east end of 16 foot, 9 inch section was taken.

2. PLAN OF THE EXAMINATION

A meeting to discuss the examination of the pipe samples was held at the National Bureau of Standards on May 30, 1979. Those attending that meeting included R. D. Stout and LeRoy C. Schlagel representing the Philadelphia Gas Works, Jerry Houck of the National Transportation Safety Board, and T. R. Shives of the NBS Fracture and Deformation Division. At that time it was agreed that the following tests and examination would be performed on the submitted pipe samples.

1) Documentary photographs of the piece of pipe containing the fracture.
2) Cleaning of the fracture surface.
3) Fractographic examination.
4) Chemical analysis of material from the piece containing the fracture.
5) Sectioning for metallographic examination and for examination for graphitization.
6) Hardness
7) Talbot and ring tests on sections of pipe furnished from three different lengths of pipe, two of which had fractured. The third length was between the two fractured lengths.

3. RESULTS OF THE EXAMINATION

3.1 Documentary Photographs

Documentary photographs of the piece of pipe containing the fracture are shown in figures 1 and 5. Documentation of the other submitted pieces of pipe are shown in figures 2, 3, and 4. Documentation of other aspects of the examination is found in other figures throughout the report.

3.2 Cleaning the Fracture Surface

The fracture surface was covered with corrosion product when received at NBS. The fracture was cleaned ultrasonically for ten minutes with a commercial detergent. Some, but not all, of the corrosion product was removed during this process. Further ultrasonic cleaning was carried out with buffered hydrochloric acid. Most of the corrosion product was removed. The fracture surface is shown after cleaning in figure 5.

3.3 Fractographic Examination

The fracture was examined macroscopically and one area was examined with the scanning electron microscope (SEM). The location of the fracture origin was not evident from the fracture features. Two SEM fractographs representative of the fracture surface are shown in figures 6 and 7. Both fractographs are at relatively low magnification since the fracture features are rather coarse. The predominant fracture mode is cleavage, indicating a low ductility or brittle fracture. This type of fracture is expected for gray cast iron. Although there had been some corrosive attack, the fracture features had not been obliterated by the corrosion process.

3.4 Chemical Analysis

Samples of material from each of the three pipe lengths examined were submitted to a commercial laboratory for chemical analysis. The results of these analyses are given below as percent by weight:

	West end, 16 ft. 9 in. length	11 ft. length	East end, 16 ft. 9 in. length
Total carbon	3.68	4.18	3.60
Combined carbon	1.04	1.65	1.29
Manganese	0.44	0.50	0.48
Phosphorus	1.34	1.45	1.35
Sulfur	0.069	0.086	0.104
Silicon	1.61	1.60	1.61
Nickel	0.03	0.03	0.03
Chromium	<0.01	<0.01	<0.01
Molybdenum	<0.01	<0.01	<0.01
Copper	0.09	0.08	0.08

The carbon equivalent[1] (% total carbon + 1/3 (% silicon + % phosphorus) for the material from all three pipe lengths is greater than 4.3% indicating that the material is hypereutectic and would be expected to be relatively low in strength. The phosphorus content in all three cases is rather high compared to today's practice. Excessive phosphorus leads to the formation of steadite (iron-iron phosphide eutectic). Steadite is hard and brittle, and if present in sufficient quantities, may have adverse effects on the mechanical properties of the cast iron. As a basis for comparison only, proposed American National Standard A21.9-1970 for cast iron pipe centrifugally cast in sand lined molds for gas service limits the phosphorus content to 0.90% maximum and the sulfur content to 0.12% maximum. It should be noted that the pipe being examined was pit cast and was produced before the quoted standard was written.

3.5 Examination for Graphitization and Metallographic Examination

Little if any graphitization was evident during a macroscopic examination of the fracture surface. A transverse section was taken through the pipe ranging from about 1/4 to 2 inches from the fracture. This section is shown in figure 8 after polishing. No significant graphitization was evident.

Two longitudinal sections intersecting the fracture were taken at the locations indicated in figure 5. A small amount of graphitization was detected adjacent to the outside pipe wall surface in these sections. A photomicrograph showing the entire wall thickness adjacent to the fracture appears in figure 9. The graphitization extends about 0.12 inch in from the outside wall surface. The wall thickness of the pipe varied around the circumference between about 0.57 inch maximum and 0.42 inch minimum. Graphitization is essentially complete right at and near the surface. As distance from the surface increases, a region of partial graphitization is reached. An area showing the change from essentially complete graphitization to partial graphitization appears in figure 10.

The unetched microstructure of the pipe material from the fractured piece is shown in figure 11. The fracture profile is horizontal at the top. The field shown in figure 11 is representative of the unetched microstructure of the material except for the region adjacent to the inside wall surface of the pipe. (The region adjacent to the inside wall surface is discussed later in this report.) The thin, dark particles are graphite flakes with a type A distribution[2].

An etched field from one of the longitudinal sections from the fractured piece of pipe is shown in figure 12. This field is representative of the material in the pipe except for the region adjacent to the inside wall surface. A field similar to that shown in figure 12 is shown at higher magnification in figure 13. The microstructure consists of graphite flakes (long, thin, dark particles), pearlite (fingerprint pattern), ferrite (light gray patches), and what appears to be steadite (small, rounded particles within the ferrite patches).

The etched microstructure adjacent to the inner wall surface is shown in figures 14 and 15. Again, the microstructure consists of graphite flakes, pearlite, ferrite and what appears to be steadite, but there is much more ferrite and much less pearlite in this region than away from the inner wall. The graphite flakes are smaller and there are more of them per unit volume than in the remainder of the material.

3.6 Hardness Measurements

An attempt was made to take Brinell hardness measurements on a transverse section through one of the two-foot pieces of pipe, but the material cracked under the load. Therefore, Rockwell K (HRK) hardness measurements were taken.

The load for hardness measurements with this hardness scale is significantly less than the load for the Brinell hardness. Ten measurements were made on one transverse section from each of the three submitted two-foot long pipe pieces. The results of these measurements and the approximate equivalent Brinell hardness number (HB) are as follows:

Pipe Identification	Hardness, HRK Range	Hardness, HRK Average	Approximate Equivalent Brinell Hardness
West end 16 foot, 9 inch length	89-94	91.7	155
11 foot length	91-93 1/2	92.2	157
East end 16 foot, 9 inch length	91 1/2 - 93 1/2	92.6	155

The typical range of Brinell hardness for ordinary gray cast iron is 140-200[1].

3.7 Ring Tests and Talbot Tests

Two ring tests and two Talbot tests were performed on specimens machined from each of the three submitted two-foot pieces of pipe in accordance with American National Standard A21.9-70. The modulus of rupture was calculated for each specimen from the results of these tests using the formulae given in ANSI 21.9-70. The results are as follows:

Pipe Identification	Modulus of Rupture, psi Ring Test	Modulus of Rupture, psi Talbot Test
West end of 16 foot, 9 inch length		
G1-1	37,300	36,400
G1-2	39,800	35,700
11 foot length		
G2-1	37,000	35,100
G2-2	40,000	37,400
East end of 16 foot, 9 inch length		
G3-1	40,000	28,300
G3-2	37,900	29,400

In addition to the modulus of rupture, the secant modulus of elasticity was calculated from the results of the Talbot tests. These results are as follows:

Pipe Identification	Secant Modulus of Elasticity, psi
West end of 16 foot, 9 inch length	
G1-1	7,110,000
G1-2	7,615,000
11 foot length	
G2-1	7,638,000
G2-2	7,350,000

East end of 16 foot, 9 inch length	
G3-1	8,625,000
G3-2	8,432,000

American National Standard A21.9-70 for cast iron pipe centrifugally cast in sand lined molds for gas requires that the modulus of rupture as calculated from the results of both ring tests and Talbot tests be at least 40,000 psi, and that the secant modulus of elasticity must not exceed 250 times the actual modulus of rupture for any given pipe sample as determined from the results of the Talbot tests.

The pipe being examined appears to have been pit cast, and not centrifugally cast, and the pipe was produced many years before the quoted standard was written. It is not clear what criteria were in effect at the time this pipe was manufactured. Therefore, although ANSI 21.9-70 is not directly applicable, it does provide a basis for comparison.

4. DISCUSSION

This eight inch diameter gray cast iron pipe natural gas main fractured transversely in three places in a region where the soil under the pipe was missing leaving the gas pipe in an unsupported condition. There was a fractured water main pipe in close proximity to the failed gas main pipe.

There was some corrosion product on the one fracture surface submitted for examination, but the corrosion product was reasonably easily removed indicating that the fracture was probably rather recent. The pipe failed in a brittle manner with cleavage being the predominant fracture mode. The location of the fracture origin was not established.

A small amount of graphitization was found at the fracture surface adjacent to the outside wall surface of the pipe. In a transverse section slightly removed from the fracture, no significant graphitization was detected. The graphitization was not considered excessive in the sections examined.

The chemical composition of the pipe material appeared to be satisfactory with the possible exception of phosphorus. The phosphorus content was higher than desirable according to today's practice. A high phosphorus content may lead to the formation of excessive steadite, a hard, brittle constituent. It may have also contributed to the high secant modulus of elasticity (relative to the modulus of rupture) for the piece of pipe from the East end of 16 foot, 9 inch length as calculated from the results of the Talbot tests. The phosphorus content, modulus of rupture from most tests, and two of the secant modulus of elasticity values would not meet today's ANSI standards for centrifugally cast iron pipe. However, it should be noted that the pipe examined was pit cast and was produced before the standard cited was written.

The hardness of the material was acceptable for gray cast iron. The microstructure of the pipe material appeared to be satisfactory, although some steadite was present. There was a region adjacent to the inside wall surface

of the pipe where the carbon content appeared to be lower than that of the rest of the material. The microstructure is also finer in this region than in the rest of the material.

5. CONCLUSIONS

1. This failed gray cast iron gas main pipe had fractured transversely in three places in a region where the soil beneath the pipe was missing.

2. Failure appeared to be due to a bending load applied to the unsupported pipe.

3. Most of the corrosion product on the fracture surface was rather easily removed, indicating that the fracture was probably recent.

4. The fracture mode was predominantly cleavage, which is normal for cast iron fractures.

5. There was some graphitization at the fracture, but not an excessive amount. Graphitization did not appear to make a significant contribution to the failure.

6. The fracture origin was not established.

7. The chemical composition of the material appeared to be typical with the possible exception of a higher phosphorus content than is usual in today's grades of cast iron.

8. The hardness of the material was typical for gray cast iron.

9. The microstructure of the material appeared to be satisfactory, with the possible exception of more steadite than desirable.

6. ACKNOWLEDGEMENT

Leonard C. Smith of the NBS Fracture and Deformation Division performed the metallographic work, prepared the SEM specimen, made the hardness measurements, and assisted in performing the ring and Talbot tests. Joel C. Sauter, also of the NBS Fracture and Deformation Division, and Mr. Smith performed the photographic work.

REFERENCES

1. Gray and Ductile Iron Castings Handbook, Gray and Ductile Iron Founder's Society, Inc., 1971.

2. Metals Handbook, 8th Edition, Volume 7, American Society for Metals, 1972.

Figure 1. Piece of eight inch diameter gray cast iron gas pipe containing one face of the fracture from the 16 foot, 9 inch length of pipe. The piece of pipe is shown as received at NBS. What was reported to be the top of the pipe as it was oriented in service is at the bottom in the figure. x 1/2

Figure 2. Two-foot length of pipe identified as being from west end of 16 foot, 9 inch length as received at NBS. This length did not contain a fracture.
X 1/3

Figure 3. Two-foot length of pipe identified as being from the 11 foot length as received at NBS. This length did not contain a fracture. X 1/3

Figure 4. Two-foot length of pipe identified as being from east end of 16 foot, 9 inch length as received at NBS. This length did not contain a fracture. X 1/3

Figure 5. Fracture surface after cleaning. What was reported to be the top of the pipe as it was oriented in service is at the top in the figure. X 2/3

Figure 6. SEM fractograph showing representative features of the fracture surface. X 19

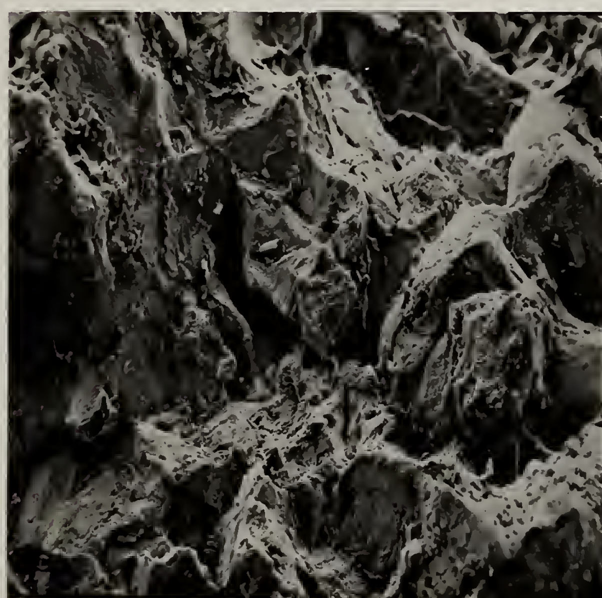

Figure 7. SEM fractograph at higher magnification than in figure 6. Cleavage is the predominant fracture mode. There is some evidence of rather mild corrosive attack. X 107

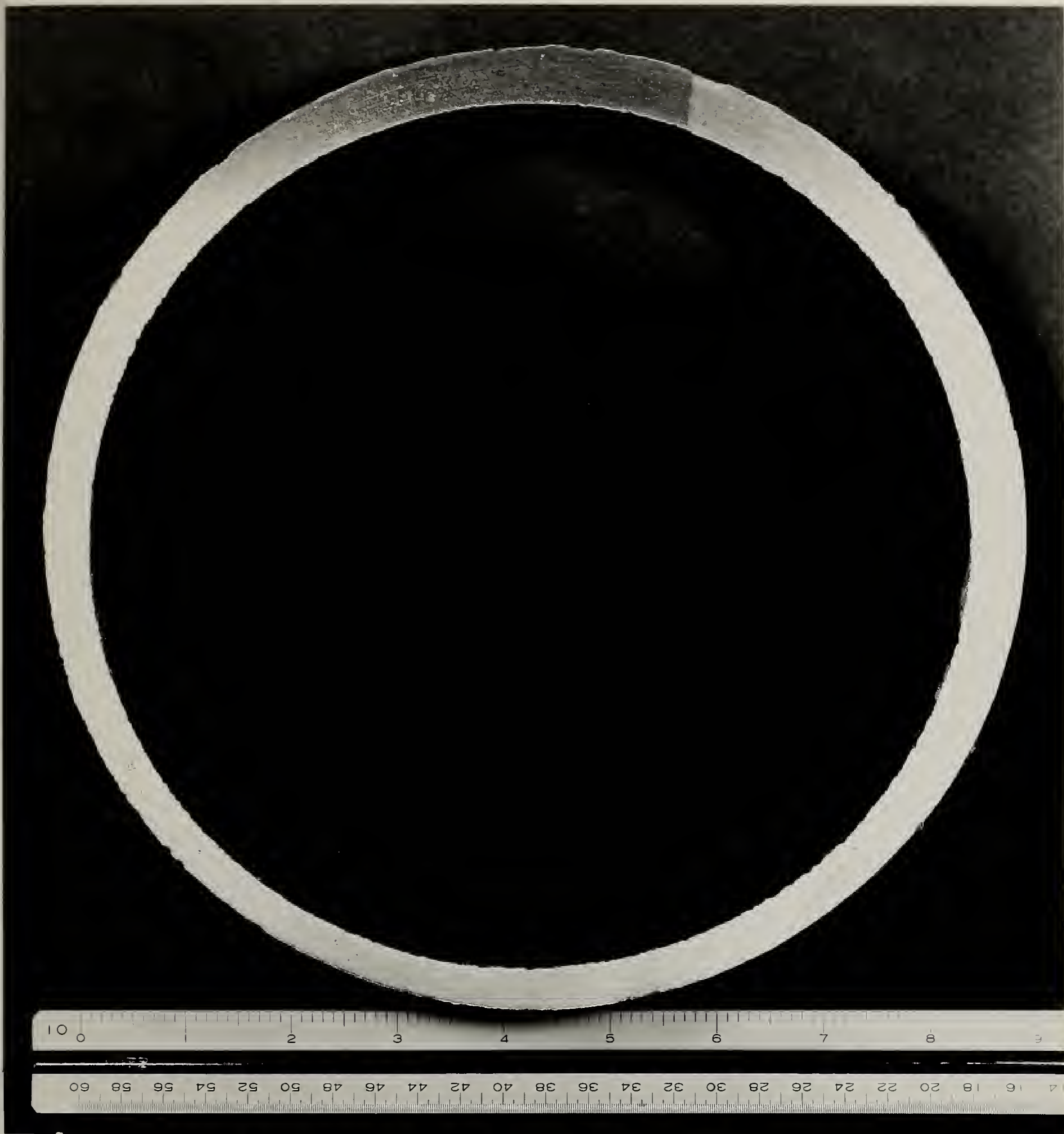

Figure 8. Polished transverse section through the piece of pipe shown in figure 1 ranging from 1/4 to 2 inches from the fracture. No significant graphitization is evident at this section. X 0.8

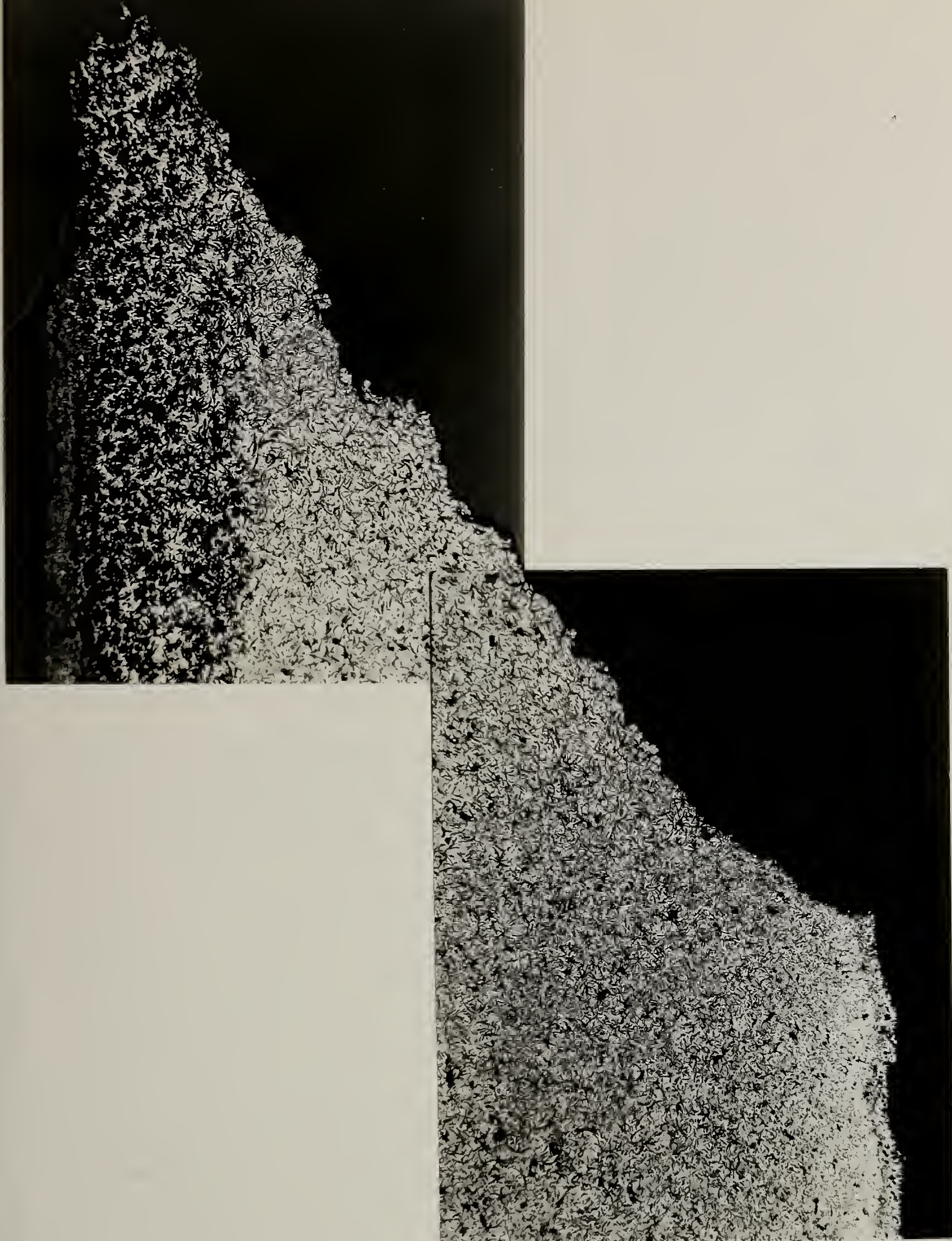

Figure 9. Etched longitudinal section intersecting the fracture at the location indicated at the lower right in figure 5. The fracture profile runs at about 45° from the upper left to the lower right. The outside pipe wall is vertical at the left and the inside pipe wall is vertical at the right. Some graphitization can be seen adjacent to the outside wall surface.
Etchant: 1% nital X 11

Figure 10. Unetched longitudinal section showing essentially complete graphitization at the left and partial graphitization at the right.
As polished X 100

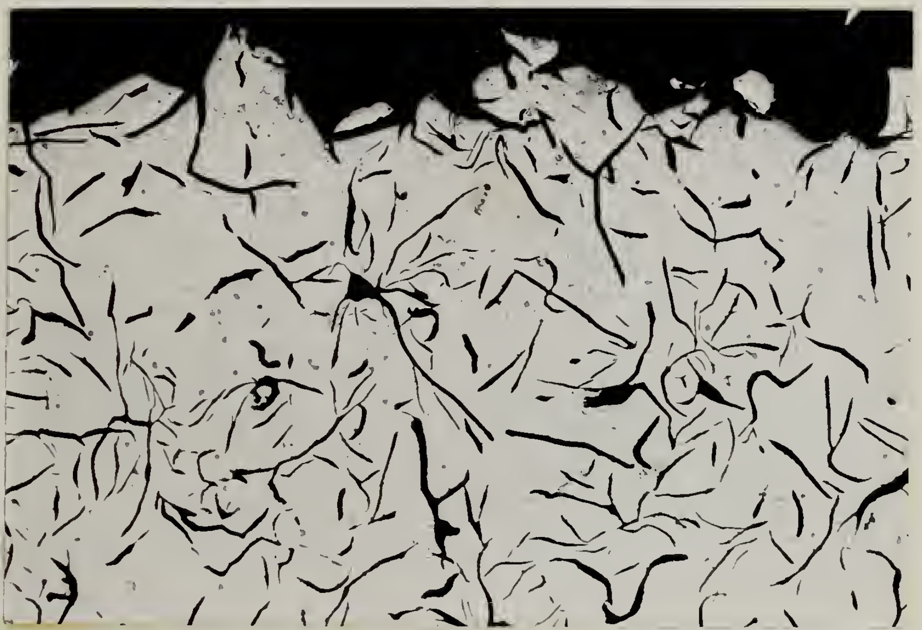

Figure 11. Unetched longitudinal section showing the fracture profile horizontally at the top. The field shown is not adjacent to either the inside or the outside wall of the pipe. The graphite flakes are present in a type A distribution.
As polished X 100

Figure 12. Etched longitudinal section showing the fracture profile horizontally at the top. This microstructure is representative of the material except for a region adjacent to the inside wall.
Etchant: 1% nital X 100

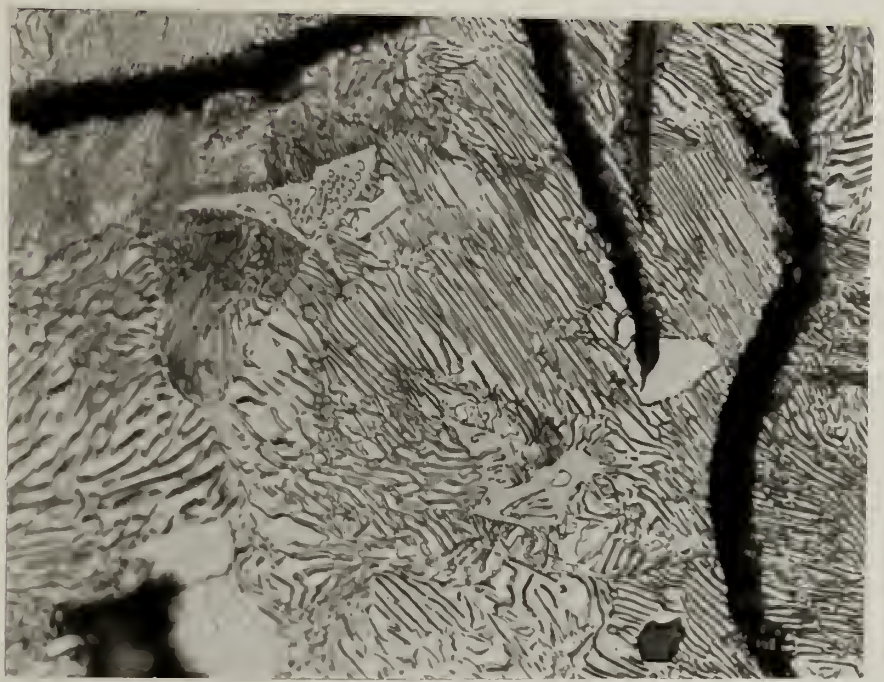

Figure 13. Etched longitudinal section showing representative microstructure of the pipe material except for the region adjacent to the inside wall. This figure is at a much higher magnification than figure 12. The microstructure consists of graphite flakes, pearlite (fingerprint pattern), ferrite (light gray patches), and what is probably steadite (small rounded region within the ferrite patches).
Etchant: 1% nital X 1000

Figure 14. Etched longitudinal section showing the fracture profile horizontally at the top. The field shown is representative of the microstructure adjacent to the inner wall of the pipe.
Etchant: 1% nital X 100

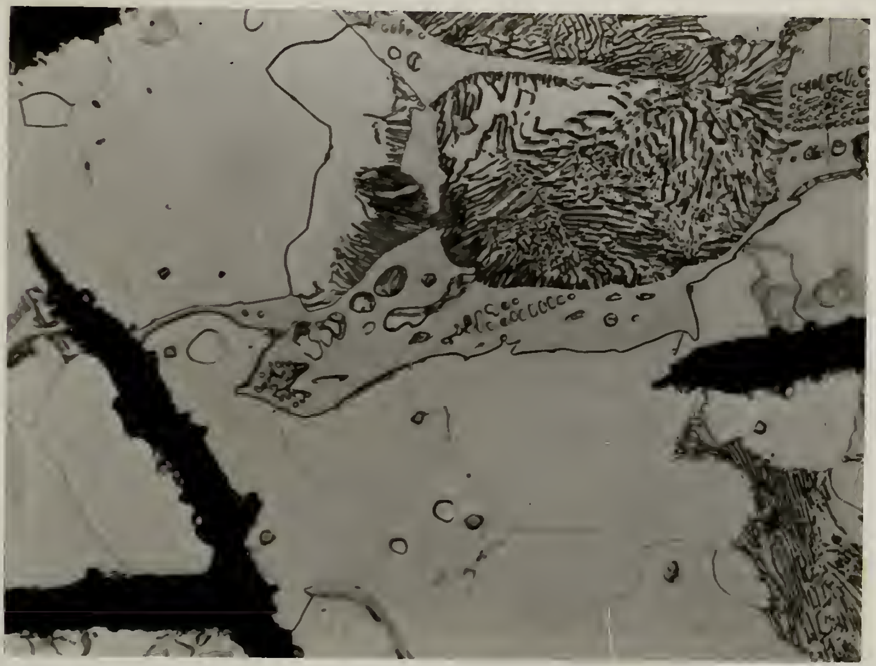

Figure 15. Etched longitudinal section showing the representative microstructure adjacent to the inner pipe wall surface. This figure is at a much higher magnification than figure 14. The microstructure consists of graphite flakes, pearlite, ferrite and what appears to be steadite.
Etchant: 1% nital X 1000

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO. NBSIR - 1985

2. Gov't. Accession No.

3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Examination of Failed Eight Inch Diameter Cast Iron Pipe Natural Gas Main, Philadelphia, Pennsylvania

5. Publication Date: Feb. 1980

6. Performing Organization Code

7. AUTHOR(S)

T. Robert Shives

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.: 5620-42

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

National Transportation Safety Board
Washington, D.C. 20594

13. Type of Report & Period Covered: Failure Analysis

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

Contract/Grant No. 5620-42

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

At the request of the National Transportation Safety Board, the National Bureau of Standards performed an examination of a fractured eight inch diameter cast iron pipe natural gas main. An explosion and fire at the location of the failure had occurred on May 13, 1979 at Tacony and Margaret Streets in Philadelphia, Pennsylvania. The supporting soil beneath the pipe was missing at the location of the failure. The pipeline had completely fractured circumferentially in three places, and after fracturing, fell into the cavity created by the missing soil.Failure appeared to be due to the application of a bending load to the unsupported pipe.

The non-uniform wall thickness indicated that the pipe was pit cast and therefore was probably rather old. Today, such pipe is normally centrifugally cast which results in a uniform wall thickness.

Only one of the fracture surfaces was selected by the National Transportation Safety Board for examination by the National Bureau of Standards. Corrosion product on that fracture surface was rather easily removed, indicating that the fracture was likely recent. Cleavage was the predominant fracture mode. The amount of graphitization at the fracture was not considered excessive.

The hardness of the material was typical for gray cast iron. The chemical composition was typical for this material, but the phosphorus content was higher than desirable according to today's practices. The microstructure appeared to be satisfactory with the possible exception of more steadite (iron-iron phosphide eutectic) than desirable according to today's practices.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Brittle fracture; Cast iron, Cast iron pipe, cast iron gas pipe, Cleavage, Graphitization

18. AVAILABILITY

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☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT): UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE): UNCLASSIFIED

21. NO. OF PRINTED PAGES: 24

22. Price: [illegible]