

NBSIR 73-264

Examination of Failed One Inch Black Iron Pipe Natural Gas Service Line, Iowa Public Service Company, Eagle Grove, Iowa

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National Bureau of Standards
Washington, D. C. 20234

August 30, 1973

Failure Analysis Report

Prepared for
Office of Pipeline Safety
Department of Transportation
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SUMMARY

A fractured one inch black iron pipe natural gas service line which connected to a building involved in an explosion and fire in Eagle Grove, Iowa on February 2, 1973 was examined in order to determine the mode of fracture and whether there was a pre-existing crack.

The fracture was ductile in nature and appeared to have occurred due to bending stresses caused by loading from an external source. There was no evidence found to indicate the presence of a pre-existing crack.

The material in the submitted pipe was clean with few inclusions. The microstructure appeared normal for a very low carbon steel in the normalized heat treatment condition.

The pipe appeared to satisfy currently applicable ASTM standards for ultimate tensile strength (determined indirectly from hardness measurements) for grade A electric resistance welded steel pipe, and carbon content (by visual comparison of microstructures) for both grades A and B electric resistance welded steel pipe.

Examination of Failed One Inch Black Iron
Pipe Natural Gas Service Line, Iowa Public
Service Company, Eagle Grove, Iowa

1. INTRODUCTION

1.1 Reference

Office of Pipeline Safety, Department of Transportation, Washington, D. C. This investigation was conducted at the request of Mr. Lance F. Heverly of OPS under order number DOT-AS-10041. The request was made on February 28, 1973.

1.2 Background Information

The information in this section was furnished by Mr. Lance F. Heverly of the Office of Pipeline Safety.

At 6:18 P.M. on February 2, 1973, there was an explosion followed by a fire that destroyed two buildings and severely damaged another at 218-222 West Broadway Street, Eagle Grove, Iowa. An accumulation of natural gas apparently provided an atmosphere conducive to explosion and fire. At the time of the incident, the ground was frozen. Pressure in the Eagle Grove gas distribution system in that area was seven psig.

Two days after the incident, the service line to one of the destroyed buildings was pressure tested for gas leaks. At the time of the explosion, the building wall had fallen on the service line above ground outside the building, and a bulldozer had apparently hit the service line inside the basement before the leak test was performed. Two leaks were found. One of these was in the threaded portion of a horizontal pipe at the downstream edge of a buried 90° elbow located just outside the basement wall of the building. The riser pipe and the elbow were broken off by fracturing the horizontal pipe at the edge of the elbow. At the point of fracture, the pipe was about two feet deep in the ground. The horizontal piece was removed with a mass of concrete attached to it. The concrete had apparently been used to fill a void in the stone wall around the service line. The void was evidently produced when the line was installed.

Examination of the fracture surfaces of the one inch pipe service line by an OPS representative in the field indicated a superficial coating of rust on both surfaces, except for one mating area on each surface where the rust appeared to be denser. The region of densest rust (corrosion product) was between the 6 o'clock and 9 o'clock positions when looking into the downstream end of the 90° elbow with the pipe positioned as it had been in service.

1.3 Parts Submitted

Two items were submitted for examination: 1) the length of one inch black iron riser pipe connected to the 90° elbow which in turn was connected to one end of the fractured horizontal one inch black iron pipe, and 2) the remainder of the fractured horizontal pipe to which the mass of concrete was attached. These parts are shown as received at NBS in figure 1. The material was delivered to the NBS Mechanical Properties Section by Mr. Heverly on February 28, 1973.

2. PURPOSE

The Office of Pipeline Safety, DOT, requested that the Mechanical Properties Section, NBS, determine the nature of the fracture, whether there had been a pre-existing crack, and the probable cause of failure.

3. EXAMINATIONS, TESTS, AND MEASUREMENTS PERFORMED

Several tests were performed in order to produce fracture surfaces for comparison with the submitted fracture surfaces. These tests, all conducted at about 70° F, were as follows:

- A) A ten inch length of stock, standard weight, one inch diameter black iron pipe threaded at one end tested to fracture in bending as shown in figure 2.
- B) A ten inch length taken from the submitted horizontal fractured pipe threaded at one end tested to fracture in bending in the same manner as in "A" above.
- C) An eleven inch length of stock, standard weight, one inch diameter black iron pipe threaded at both ends and pulled to fracture in uniaxial tension as shown in figure 3.
- D) An eight inch length taken from the undamaged remainder of the bend test specimen threaded at both ends and pulled to fracture in uniaxial tension as in "C" above.

The fracture surfaces of the submitted failure and the failures produced in "A" through "D" above were examined visually and macroscopically. Selected areas of the fracture surfaces of the submitted failure and of test pieces from "B" and "D" were examined with the scanning electron microscope (SEM). In addition, cross sections, some of which intersected the fracture surfaces of the submitted fracture and the NBS produced fractures "A", "B", and "D", were examined metallographically. Hardness measurements were made on transverse cross sections through the submitted failure and the stock black iron pipe.

Specimens for SEM examinations, for tests "B" and "D", and the cross sections for hardness measurements and metallographic examinations from the submitted failed pipe were all taken from the long portion of the horizontal pipe piece to which the concrete had been attached. The small threaded portion of the horizontal pipe that remained in the elbow was examined visually and macroscopically, but was otherwise undisturbed.

4. RESULTS OF EXAMINATIONS, TESTS AND MEASUREMENTS

4.1 Visual and Macroscopic Examination

4.1.1 Submitted fracture

The two opposing fracture surfaces of the submitted failure are shown as received in figure 4. The pipe had fractured in the threaded end at the root of a thread at the end of a 90° elbow as can be seen in figure 4a. The short part of the fractured piece remained in the elbow.

The concrete was removed from the horizontal pipe piece in order to examine the entire submitted length. The horizontal piece, the riser, and the elbow were all covered with what appeared to be a mixture of fiberglass and coal tar. The pipe appears to have been fabricated by an electric resistance welding process.

Both of the fracture surfaces were covered with corrosion product (rust) which for the most part appeared to be superficial except for the region discussed in Section 1.2 where the rust appeared to be denser. This region was between the 6 o'clock and 9 o'clock positions when looking into the downstream end of the 90° elbow with the pipe positioned as it had been in service. The heaviest concentration was at about the 7-7:30 o'clock position (arrow A, figure 4a). The dense rust appeared on the mating position of the opposing fracture surface (arrow A, figure 4b). There were mating areas on both fracture surfaces adjacent to the region of densest rust which appeared to have suffered mechanical damage (arrows B, figure 4). The apparent last part to fail is indicated by arrows C, figure 4.

4.1.2 NBS produced fractures

Each of the four pipe specimens tested at NBS ("A" through "D", Section 3) failed at the root of a thread adjacent to the outside of the threaded fixture to which it was attached for testing. A considerable amount of ductility was exhibited in each case.

After the submitted fracture surface was cleaned, the appearance of it and the appearance of the NBS produced fracture surfaces were very similar. The tearing and deformation at the apparent last part to fail in the submitted fracture (arrow C, figure 4a) more closely approximated that of the NBS bend test fractures than those produced by uniaxial tensile testing. Since the rust was easily removed from the submitted fracture by ultrasonic cleaning with water and detergent, the rust over the entire fracture surface was apparently superficial.

4.2 Scanning Electron Microscope Examination

The submitted failure and the NBS produced failures "B" and "D" all exhibited dimpled rupture over essentially their entire fracture surfaces indicating that all the fractures were ductile in nature. Scanning electron photomicrographs (SEM's), showing features representative of the submitted fracture, are shown in figures 5 through 9. Figures 5 and 6 were taken in an area which appeared to exhibit the densest rust (area A, figure 4b). They show dimpled rupture. Figure 7 (area B, Figure 4b) shows dimpled rupture with considerable mechanical damage. The edge of the thread root can be seen near the bottom of the figure. Figures 8 and 9 were taken in two different areas away from that exhibiting the dense rust. Dimpled rupture again is essentially the only fracture feature exhibited. No evidence was found to indicate the presence of a pre-existing crack.

SEM photomicrographs representative of the fracture features of specimens from "B" and "D" are shown in figures 10 and 11, respectively. Both fracture surfaces exhibited essentially all dimpled rupture.

4.3 Metallographic Examination

Figure 12 shows a representative unetched field from a longitudinal cross section through the submitted failed pipe. The concentration and size of the inclusions are small and are not considered excessive for this material.

Low magnification photomicrographs of etched, longitudinal sections showing fracture profiles of the submitted failure and NBS produced failures "B" and "D" are shown in figures 13a, b, and c, respectively. The fracture profile in each case is shown vertically at the right of the figure. A considerable amount of deformation and necking can be seen in all three specimens, indicating ductility in the material. Some

deformation was exhibited in the interior of the cross section adjacent to the root of the first thread beyond the fracture of the submitted failure (figure 14). Some of the deformation near the surface at the thread root appears to have been induced into the material by the threading operation. There are a few large stringers (inclusions) in this field which is not typical of the material in the submitted pipe.

An etched microstructure representative of the material away from the deformed regions is shown in figure 15. The microstructure consists of ferrite (white) and a small amount of pearlite (dark patches). This is the microstructure of a normalized very low carbon steel.

Metallographic examination of the stock black iron pipe material revealed a considerably higher inclusion content than found in the submitted material. An etched microstructure from a longitudinal cross section through the stock pipe is shown in figure 16. The microstructure consists of ferrite (white) and pearlite (dark patches). There is some evidence of a Widmanstätten structure. Comparison of microstructures indicates that the material from the stock pipe has a significantly greater amount of pearlite, and consequently, a significantly higher carbon content than that of the submitted pipe.

4.4 Hardness Measurements

The Rockwell hardness of the submitted pipe ranged from R_{45T} 23 to 30.5 (based on 18 measurements) while that of the stock pipe ranged from R_{45T} 32 to 38 (based on eight measurements).

5. DISCUSSION OF RESULTS

Even though there were relatively small areas of fairly dense rust on the opposing fracture surfaces of the submitted failure, the rust was easily removed when the fracture was cleaned with detergent and water in an ultrasonic cleaner. A fractographic examination revealed no evidence to indicate the presence of a pre-existing crack in the pipe. The fracture was quite ductile, with dimpled rupture being essentially the only fracture feature exhibited (except for some mechanical damage).

When tested to failure both in bending and in tension, samples of the stock black iron pipe and samples from the submitted failed pipe produced fractures which exhibited dimpled rupture as essentially the only fracture feature present. This indicates that all the fractures were ductile. The bend specimens had more of a tear lip than did the tensile specimens. Comparison of the submitted fracture to the NBS produced fractures indicated that the failure in the submitted pipe was probably due to bending stresses caused by loading from an external source.

The microstructure of the submitted pipe material, consisting of ferrite and pearlite, appears to be normal for a normalized very low carbon steel. An ASTM specification giving heat treatment requirements for black iron pipe could not be found.

One of the ASTM Standards¹ which currently applies to pipe of the type used in applications such as that of the submitted pipe specifies a maximum carbon content of 0.25% for grade A and 0.30% for grade B. There is no minimum carbon requirement. The microstructure of the submitted pipe indicates that the carbon content is well below the maximum allowed.

The greater hardness of the stock pipe compared to the submitted pipe is probably due to the higher carbon content of the stock pipe. There appear to be no hardness requirements in the ASTM Standards.

The current strength requirements^{1, 2, 3} for electric resistance welded steel pipe specify a minimum ultimate tensile strength of 48 ksi for grade A pipe and 60 ksi for grade B pipe. The approximate ultimate tensile strength equivalent to an average Rockwell 45T hardness of 26.7 (as determined for the submitted pipe) is about 49 to 50 ksi⁴ when compared to data for an AISI 1008 steel. The pipe material thus appears to satisfy current ultimate tensile strength requirements for grade A electric resistance welded steel pipe.

6. CONCLUSIONS

1. The fracture of the submitted pipe was essentially completely ductile, dimpled rupture being the only fracture feature exhibited (except for some mechanical damage).

2. Since the rust was easily removed in an ultrasonic bath with water and detergent, it was essentially all of a superficial nature.
3. There was no evidence to indicate the presence of a pre-existing crack.
4. Comparison of the submitted fracture with laboratory produced fractures indicates that the submitted failure was probably due to bending caused by loading from an external source.
5. The carbon content and ultimate tensile strength of the material from the submitted pipe appear to satisfy current ASTM requirements for grade A electric resistance welded steel.
6. The microstructure appears normal for a normalized very low carbon steel.

7. ACKNOWLEDGEMENT

Dr. M. L. Picklesimer, Chief of the NBS Mechanical Properties Section, provided a number of suggestions for the conduct of this investigation. Mr. L. C. Smith, also of the NBS Mechanical Properties Section, prepared the specimens for the mechanical tests and for the metallographic and SEM examinations.

REFERENCES

- ¹ ASTM Standard A53-71, American Society for Testing and Materials, Book 1, 1972.
- ² ASTM Standard A120-71, American Society for Testing and Materials, Book 1, 1972.
- ³ ASTM Standard A135-69, American Society for Testing and Materials, Book 1, 1972.
- ⁴ Metals Handbook, 8th Edition, Volume 1, American Society for Metals, 1961.



Figure 1. Submitted failed natural gas service line pipe parts as received. ~ X 1/4

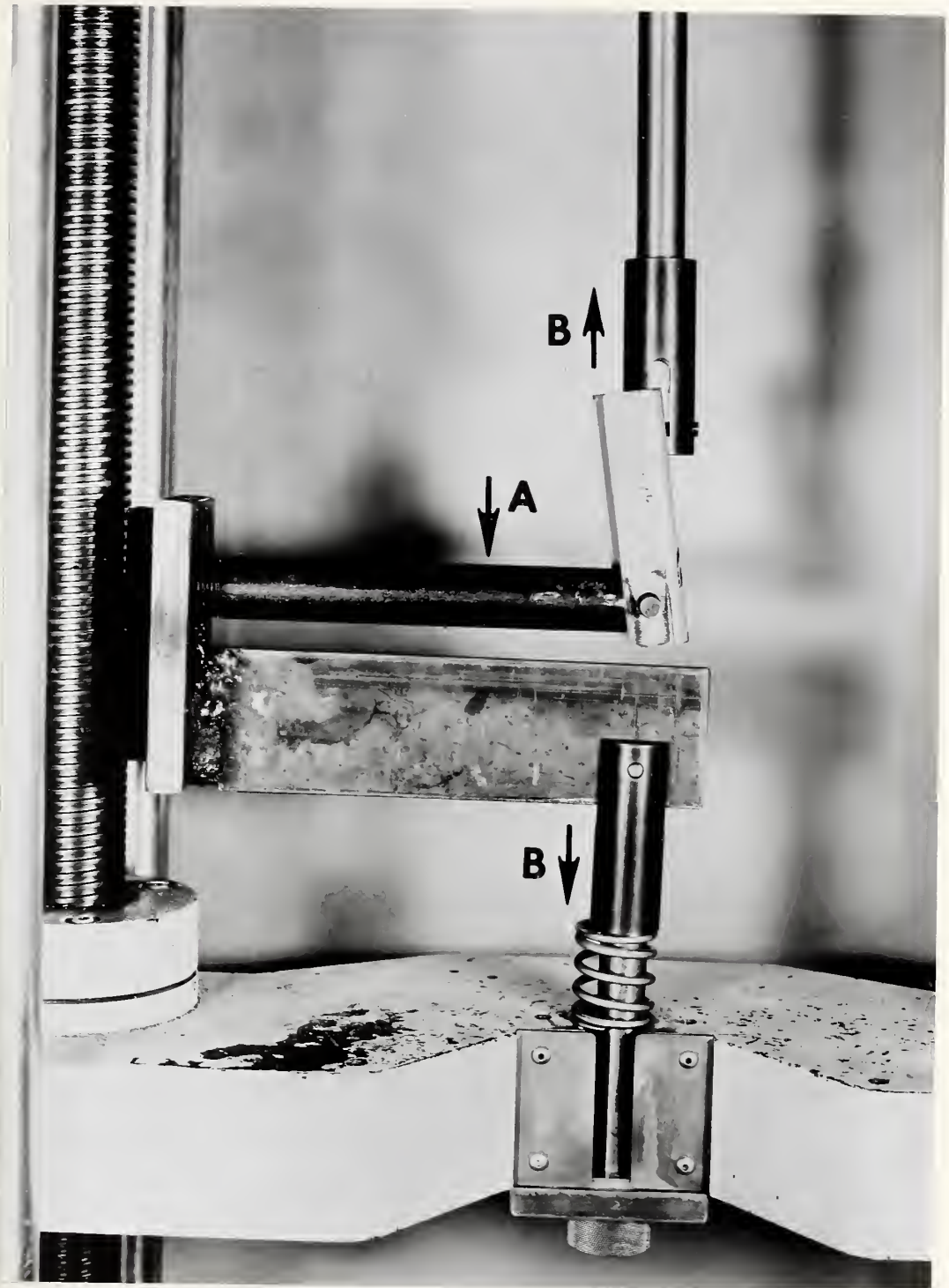


Figure 2. Setup for bend test of pipe length. Pipe specimen is indicated by arrow A. Arrows B indicate the direction of load application. The specimen is threaded on the left end.

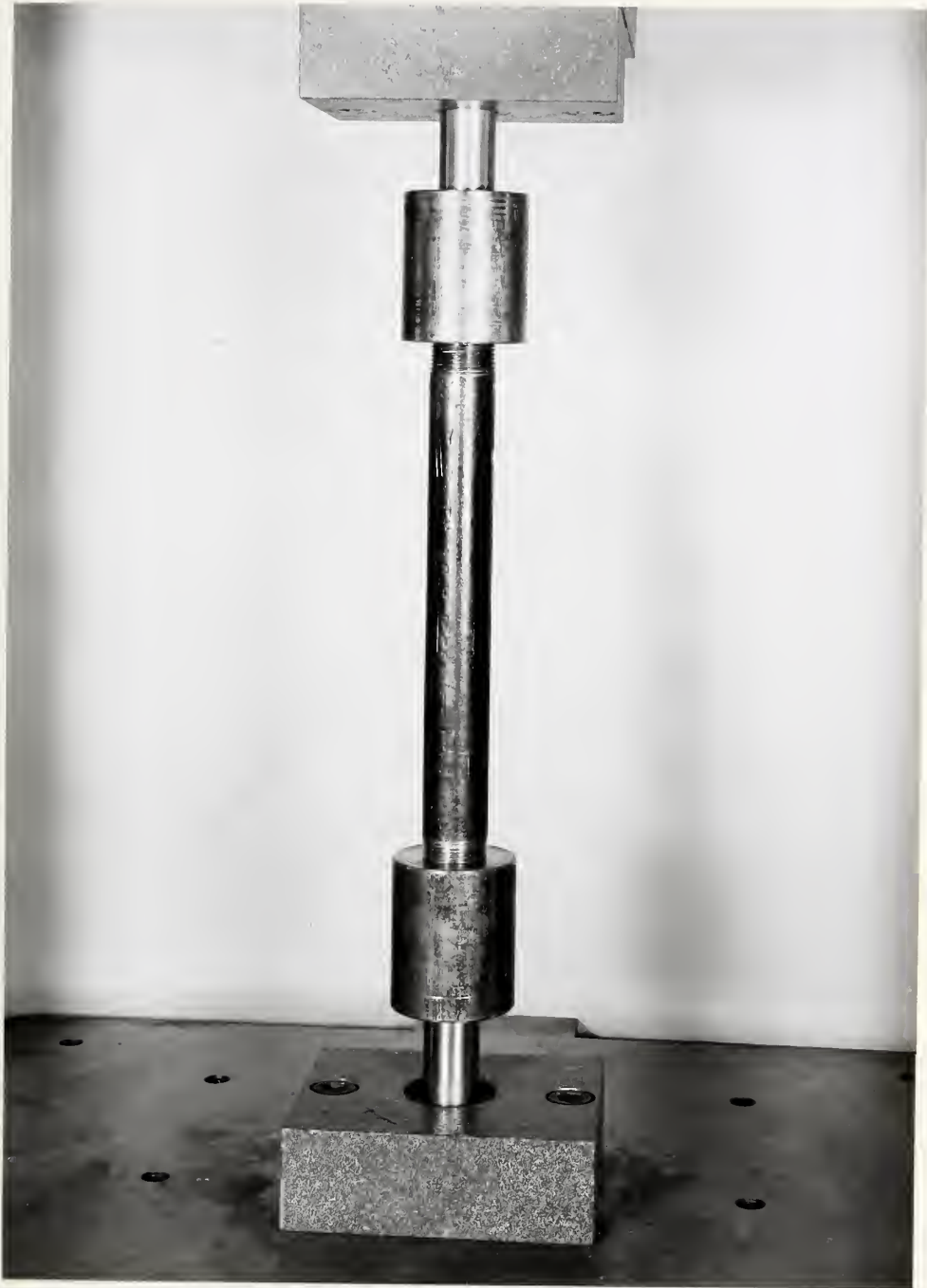
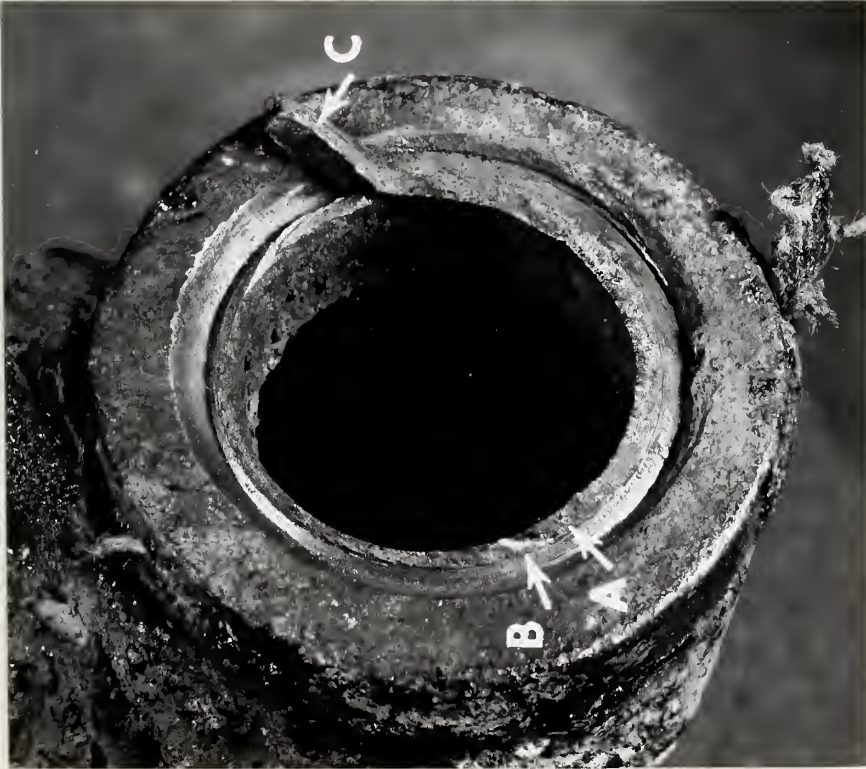
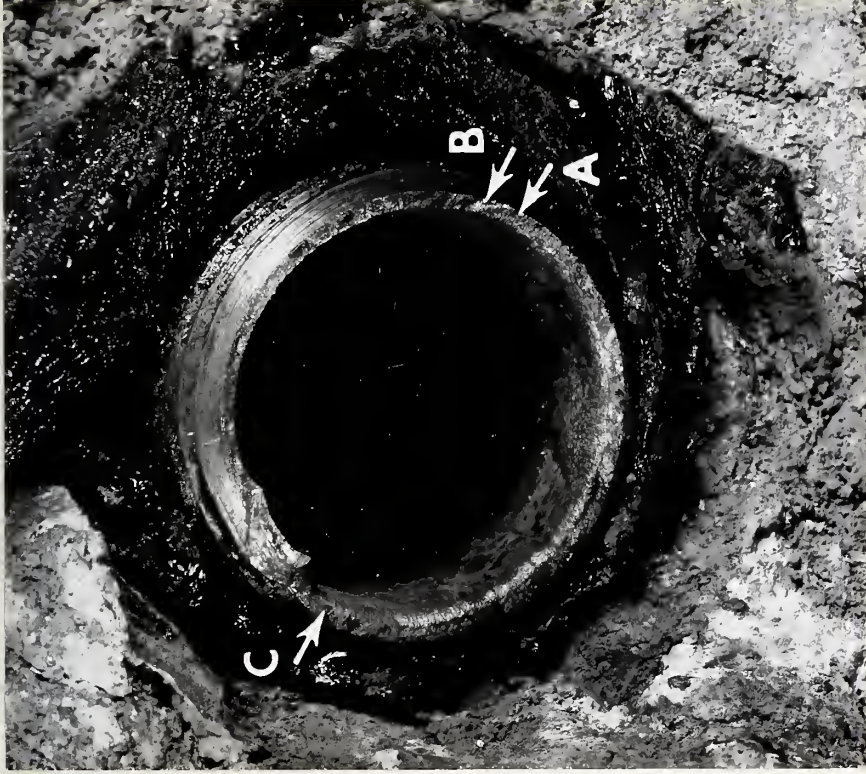


Figure 3. Setup for uniaxial tensile test of pipe length. Pipe is threaded on both ends.



a



b

Figure 4. Fracture surfaces of the submitted failure as received. Arrows A indicate areas of dense rust; arrows B indicate areas of mechanical damage; arrows C indicate apparent last part to fail. X 2

a. Fracture surface of part of the horizontal pipe which remained in the 90° elbow. The elbow was attached to the riser pipe.

b. Fracture surface of the remainder of the horizontal pipe.

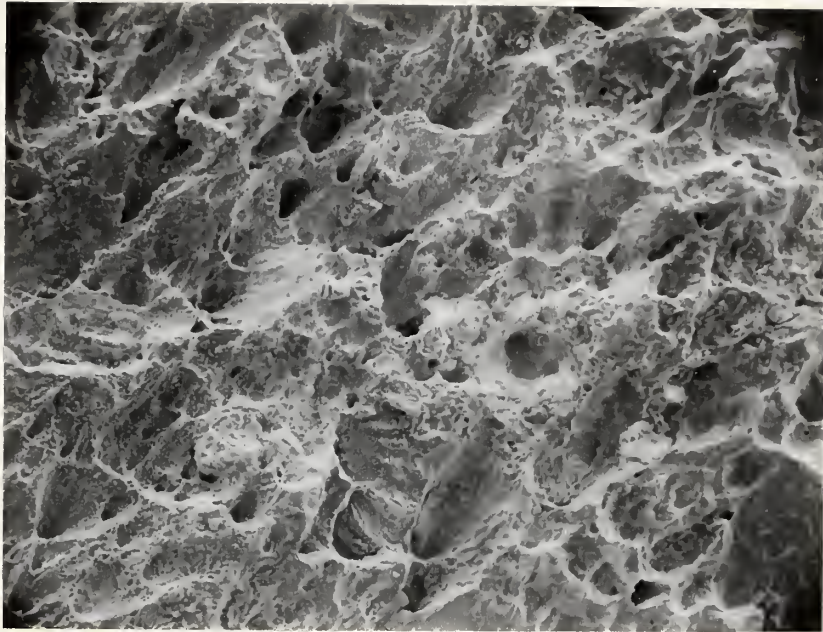


Figure 5. SEM of the fracture surface of the submitted failure in the area of densest rust (area A, figure 4b) showing dimpled rupture. X 650

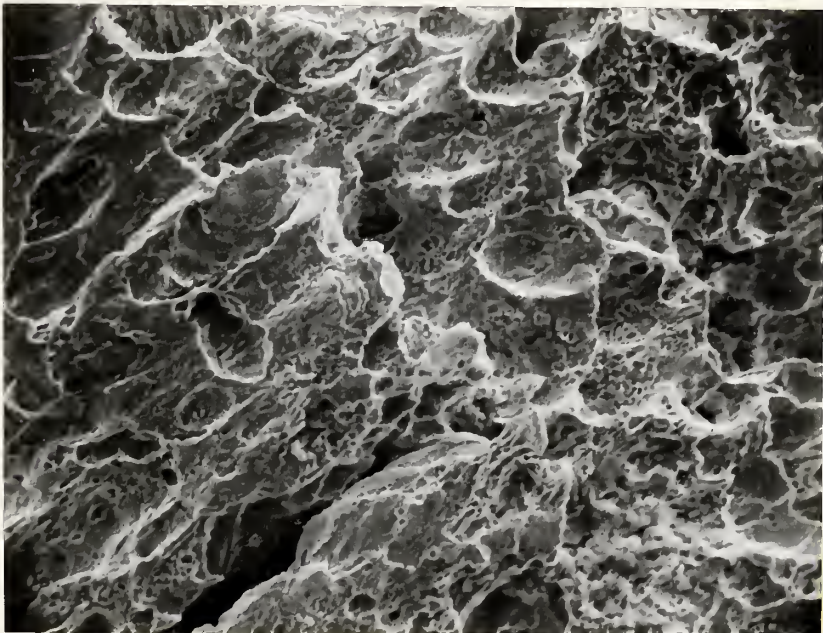


Figure 6. SEM of the fracture surface of the submitted failure in the area of densest rust (area A, figure 4b) showing dimpled rupture. A secondary crack can be seen in the lower left portion of the figure. X 1300

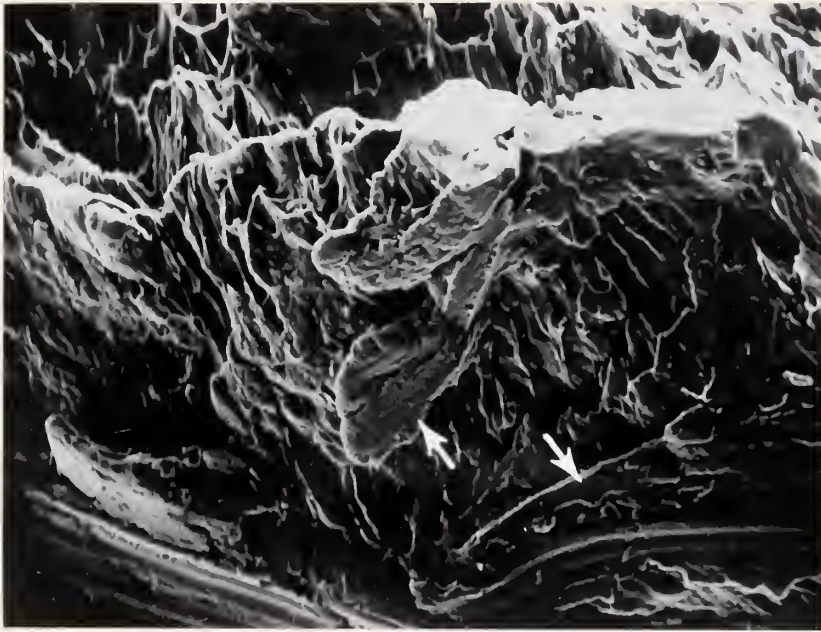


Figure 7. SEM of the fracture surface of the submitted failure in area B, figure 4b, showing mechanical damage (arrows) and dimpled rupture. Edge of thread root can be seen at lower left. X 550

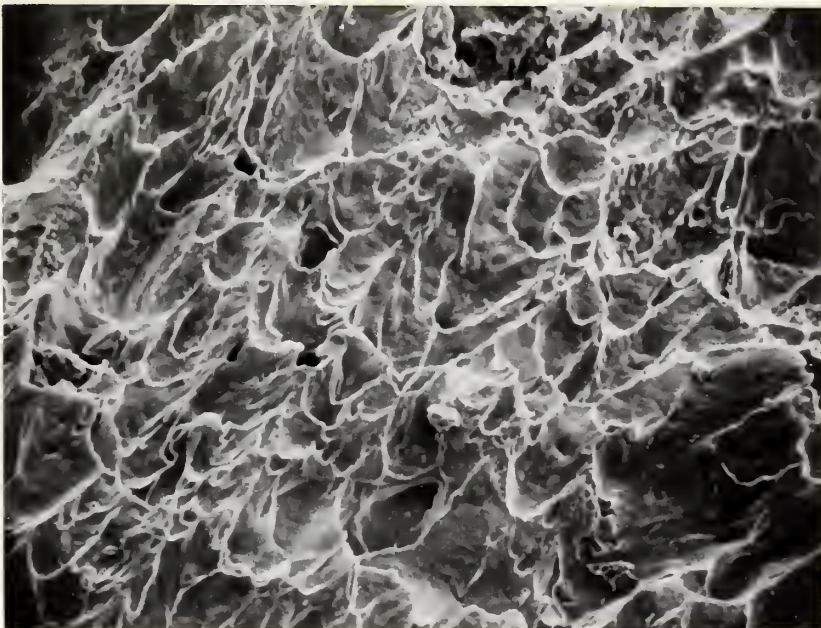


Figure 8. SEM of the fracture surface of the submitted failure in an area away from that containing the densest rust showing dimpled rupture. X 1100

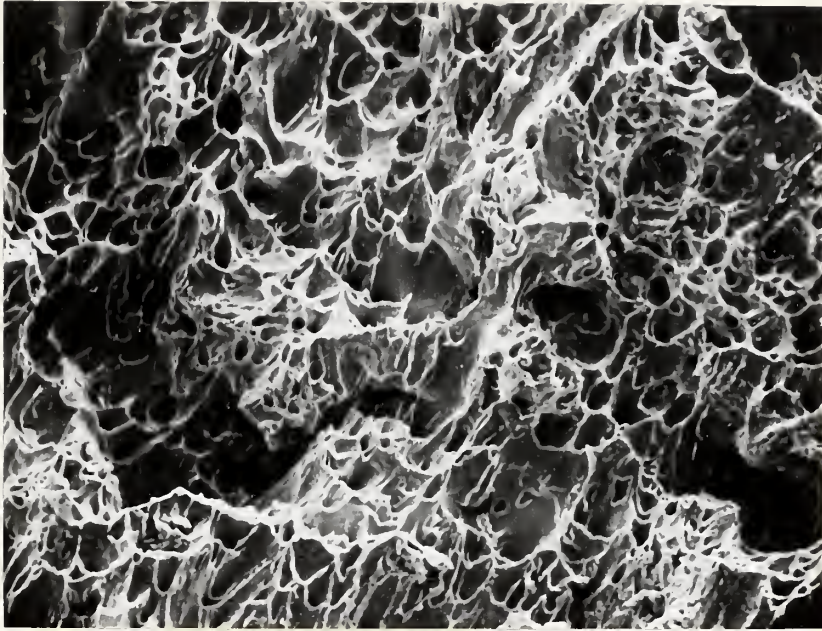


Figure 9. SEM of the fracture surface of the submitted failure in an area away from that containing the densest rust showing dimpled rupture. X 600



Figure 10. SEM of the fracture surface of the NBS produced bend test (test B) showing dimpled rupture. X 550

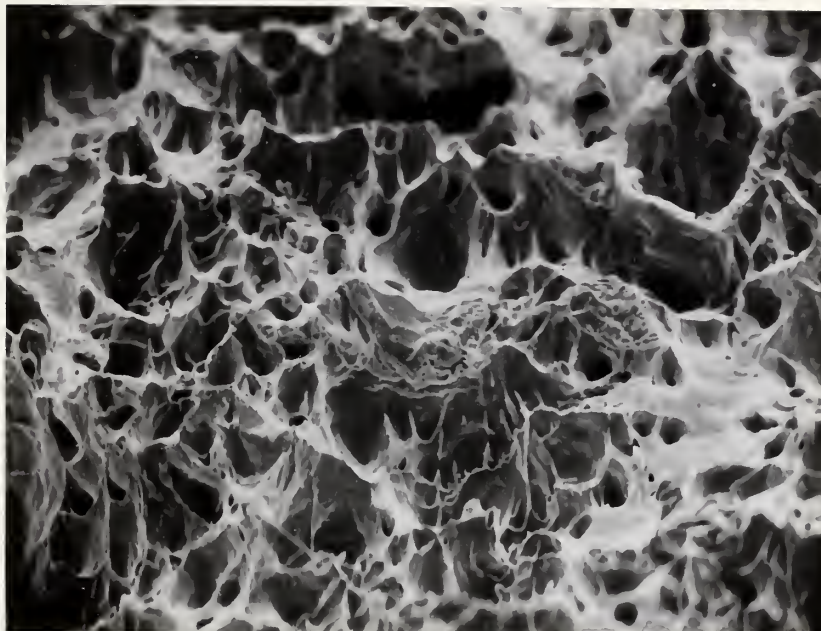


Figure 11. SEM of the fracture surface of the NBS produced uniaxial tensile test of material from the submitted failure (test D) showing dimpled rupture. X 750

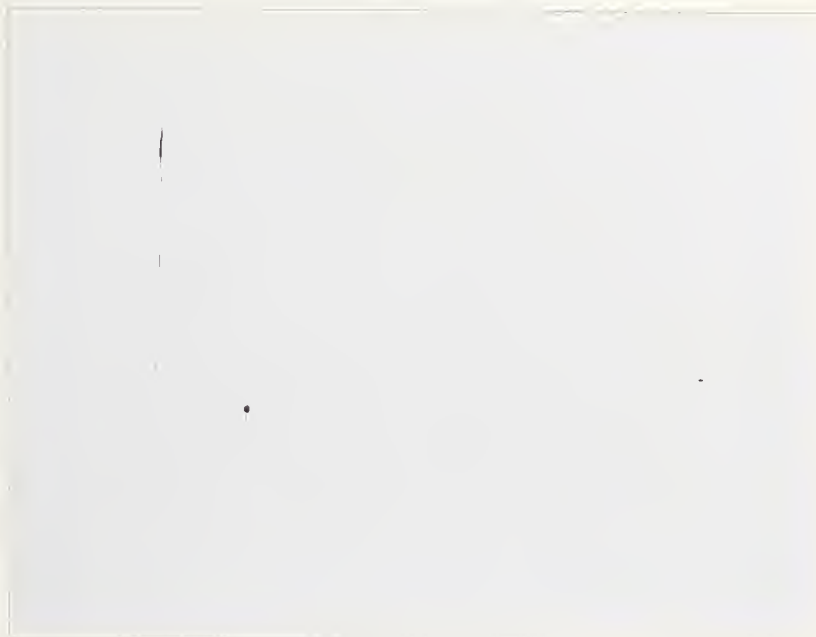
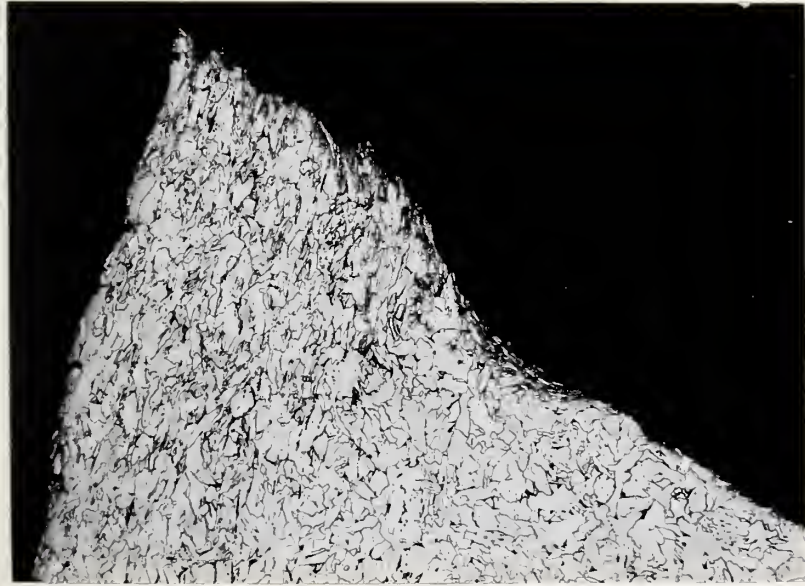
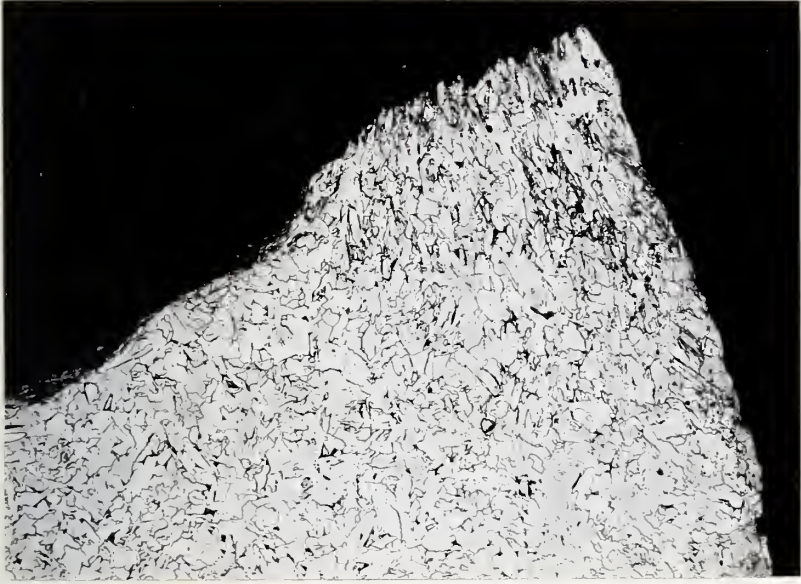


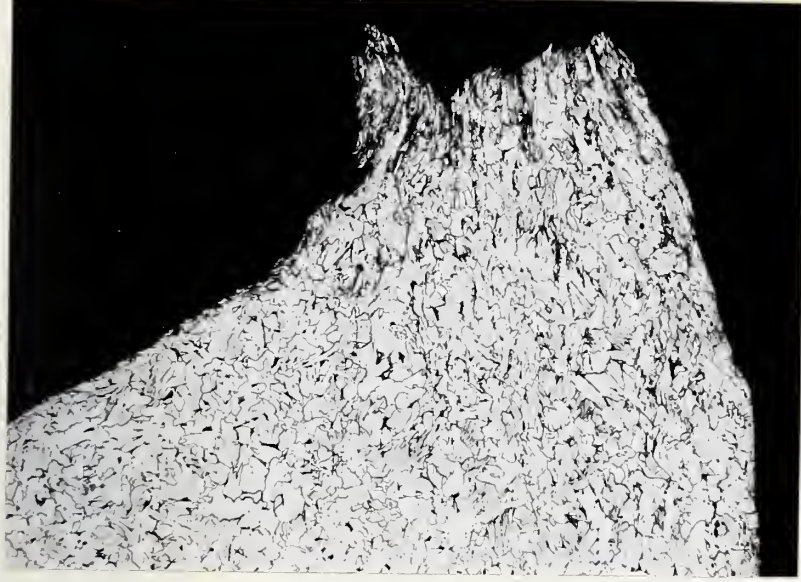
Figure 12. Unetched longitudinal cross section through the submitted failed pipe showing the representative inclusion content. X 100



a



b



c

Figure 13. Etched longitudinal cross sections showing fracture profiles. The inside wall surface of the pipe is horizontally at the top in 13a and horizontally at the bottom in 13b and 13c. The fracture profiles are vertically at the right in each case. Etch: ammonium molybdate. X 40

- a. Submitted failure.
- b. NBS bend test "B".
- c. NBS tensile test "D".



Figure 14. Etched longitudinal cross section through submitted fractured pipe showing deformation at and near the root of the thread one thread removed from the fracture. Etch: ammonium molybdate. X 100

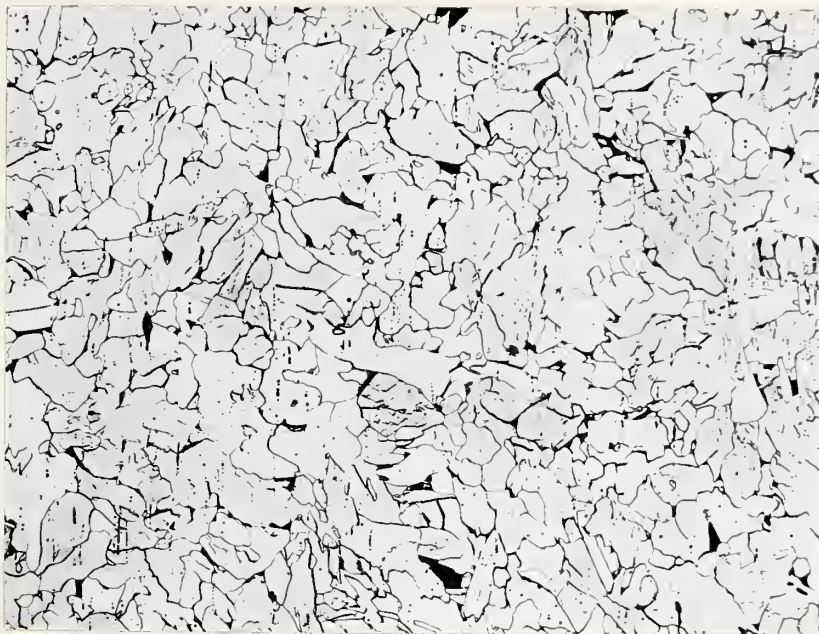


Figure 15. Etched longitudinal cross section through submitted failed pipe showing representative microstructure which consists primarily of ferrite (white) and a small amount of pearlite (dark patches).
Etch: ammonium molybdate. X 100

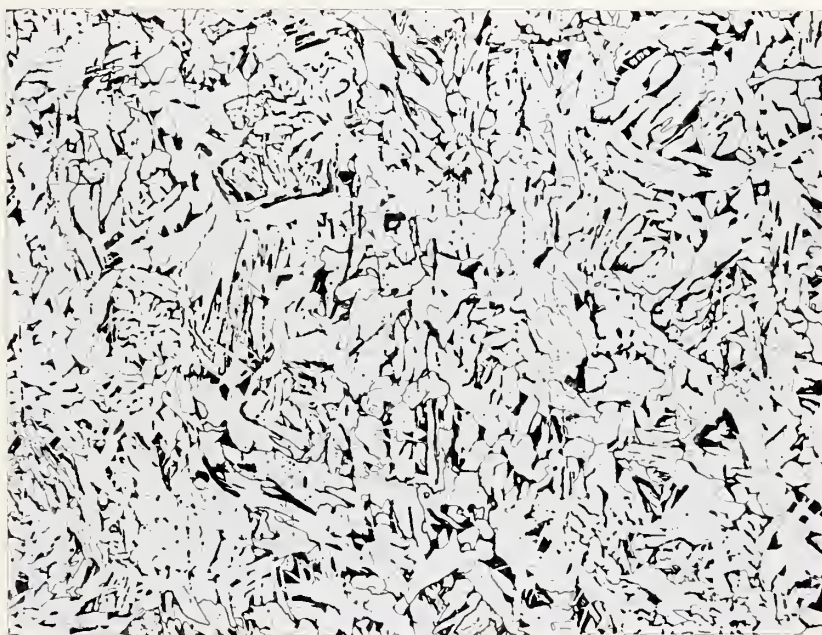


Figure 16. Etched representative longitudinal cross section through stock standard weight black iron pipe used for tests A and C. The microstructure consists of ferrite (white) and pearlite (dark patches). There is some evidence of a Widmanstätten structure.
Etch: 3% Nital. X 100

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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.) A fractured one inch black iron pipe natural gas service line which connected to a building involved in an explosion and fire in Eagle Grove, Iowa, on February 2, 1973, was examined by the NBS Mechanical Properties Section. The fracture was ductile in nature. There was no evidence found to indicate the presence of a pre-existing crack. The fracture appeared to have been due to bending stresses caused by loading from an external source.			
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