REC-ERC-84-3

EROSION STUDIES OF PIPE LINING MATERIALS FIFTH PROGRESS REPORT

May 1984

Engineering and Research Center

partment of the Interior
Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
REC-ERC-84-3		

4. TITLE AND SUBTITLE	5. REPORT DATE
Erosion Studies of Pipe Lining Materials Fifth Progress Report	May 1984
	6. PERFORMING ORGANIZATION CODE D-1521
7. AUTHOR(S) Henry Johns	8. PERFORMING ORGANIZATION REPORT NO. REC-ERC-84-3
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, Colorado 80225	10. WORK UNIT NO.
	11. CONTRACT OR GRANT NO.
	13. TYPE OF REPORT AND PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS Same	14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the Engineering and Research Center, Denver, CO

Ed: BDM

16. ABSTRACT

This is the fifth report on laboratory tests to evaluate the erosion resistance of the inner surface of water-bearing pipe. Erosion resistance is defined as the resistance to the wearing effect produced by abrasive particles such as would be encountered in steel pipe carrying sand or sand- and gravel-laden water. Erosive conditions are simulated by rotating a lined pipe containing a sand-water or gravel-water slurry. Coal-tar enamel has good erosion resistance and is used as the standard for comparing other materials. Seventeen RPM pipe liners, concrete, steel, synthetic and natural rubber sheet, PVC, polyethylene, and ABS pipe had better erosion resistance than coal-tar enamel; four RPM liners, three RTRP liners, and one vinyl resin liner for asbestos-cement pipe were less resistant. Results from four previous progress reports are included.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*--accelerators/ bituminous materials/ *protective coatings/ coal-tar coating/ flexible linings/ *linings/ mortar/ paints/ laboratory tests/ plastics/ red lead/ synthetic rubber/ *erosion/ measuring instruments/ materials testing/ epoxy resins/ steel pipes/ polyester resins

b. *IDENTIFIERS*-- vinyl resin coatings/ reinforced plastic pipe/ erosion resistance/ product evaluation/ *pipe linings

c. *COSATI Field/Group* 11C *COWRR:* 1103 *SRIM:*

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161. (Microfiche and/or hard copy available from NTIS)	UNCLASSIFIED	47
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

REC-ERC-84-3

EROSION STUDIES OF PIPE LINING MATERIALS
FIFTH PROGRESS REPORT

by

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May 1984

Applied Sciences Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This study was conducted under the supervision of J. L. Kiewit and B. V. Jones, retired Head and current Head, respectively, Materials Science Section. Laboratory photographs were by W. K. Lambert.

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INTRODUCTION

The tests covered in this report are a continuation of those covered by Laboratory Reports No. P-66 [1][1], P-79 [2], P-93 [3], and ChE-97 [4]. They represent an effort to evaluate the relative resistance of lining materials in steel pipe and in composite pipe to the erosive forces produced by sand- and gravel-laden water. Exposures simulated by the test conditions sometimes occur in siphon pipes having earth-lined canals upstream.

These additional tests were conducted to evaluate: sheet rubber linings for steel pipe; unlined concrete and unlined steel pipe; and a vinyl resin lining for asbestos-cement pipe, RTRP (reinforced thermosetting resin pipe), thermoplastic pipe, RPM (reinforced plastic mortar) pipe, and damaged and repaired areas in RPM pipe. As in the previous reports, erosion resistance of the materials is compared with coal-tar enamel, which is often specified for lining buried steel pipe. Erosion resistance is, of course, only one of many factors considered in the selection of pipes or pipe lining materials.

In the previous studies, a single approach was used in evaluating the lining; namely, a comparison with coal-tar enamel. In the interim between reports, it was found necessary to develop a new system specifically to evaluate composite pipes, such as RPM, wherein there is an integral but generally identifiable liner. As a result, linings of all pipes are evaluated using both approaches.

CONCLUSIONS

1. The erosion test is now well established as a means for evaluating the effectiveness of lining materials and the amount of protection to be expected from a liner.

2. A different system proposed for evaluating liners for RPM pipe is somewhat at variance with the performance rating which has been used for 20 years in evaluating lining materials for other types of pipe. Some additional study of the newer system, which is essentially "pass-fail," should be considered. Specifically, changes which will provide test results which give an indication of performance more closely in line with the present system should be investigated.

3. Test results on the newest liner for RPM pipe, an unfilled isophthalic polyester resin compound, show it to be acceptable. However, it is less erosion resistant than the previous aluminum silicate-filled isophthalic polyester resin material. The new liner is reported to be more flexible than older materials.

4. Damage repairs for RPM pipe are satisfactory for erosion resistance and for presenting a barrier to water, but no study was made to evaluate the ability of the patches to restore structural strength.

5. The vinyl solution tested for use in asbestos-cement pipe to serve as a barrier to soft water was not erosion resistant, nor was it an impermeable barrier.

6. Sheet rubber liners are probably the ultimate in erosion resistance.

7. All of the thermoplastic pipes — PVC (polyvinyl chloride), ABS (acrylonitrile butadiene styrene), and PE (polyethylene) — were more erosion resistant than coal-tar enamel, sometimes in a ratio of 10 to 1.

8. The less time-consuming single erosion procedure, where only No. 4 aggregate and water are used as the erosive medium and where duration of the test is extended about 28 percent, is equivalent to the four-run sand and gravel runs previously done.

APPLICATIONS

When this program was started in 1954, the main purposes were to determine the relative resistance to erosion of lining materials for steel pipe then in common use and to evaluate other proprietary coatings which were reputed to be suitable for use in erosive environments. There were at that time essentially five standard protective coatings for use where corrosion was the main problem and erosion or abrasion were lesser considerations: red lead priming paint (Federal specifications TT-P-86a, type IV), cement-mortar, coal-tar enamel, vinyl resin paint VR-3, and vinyl resin paint VR-6. Only coal-tar enamel and cement-mortar were indicated to have good erosion resistance, VR-6 was moderate, VR-3 low, and the red lead priming paint poor, both in those tests and in field installations.

Coal-tar enamel or cement mortar would, therefore, appear to be the most suitable lining materials since their corrosion resistance has already been well established. Unfortunately, coal-tar enamel does not provide satisfactory service in sunlight exposures; neither coal-tar enamel nor cement mortar are satisfactory in locations where they are subject to wide variations in temperature such as would be the case of a steel siphon above ground. Vinyl resin paint (VR-3) provides good corrosion protection but has low erosion resistance, which is at least partly due to its low film thickness [0.15 mm versus 1.59 mm (6 mils versus 62-1/2 mils) for coal-tar enamel]. Since it is not feasible to apply 20 or more coats to develop appreciable thickness, the approach used was to embed sand in the vinyl

[1] Numbers in brackets refer to entries in bibliography.

paint. It was found that a four-coat VR-3 system having 20-30 mesh Ottawa silica sand in the third coat has good erosion resistance and was the best of several systems tested. The four-coat VR-3 with 20-30 mesh sand was used for paving the invert in the Malheur River Siphon, Owyhee Project, and provided satisfactory service for many years. Sheet rubber linings, such as those included in this test series, have been found in the past to provide excellent erosion resistance but are quite expensive and, therefore, suitable for only specialized locations. Liquid-applied neoprene rubber materials also have mostly been found to have good erosion resistance. The most likely of the newer materials are the polyurethane coatings which can be applied in thicknesses up to 1.0 mm (40 mils) in one multipass coat.

The main emphasis in pipe covered by this report was on glass fiber RTRP and on RPM pipes. Of the 41 pipes tested, 25 fell into this category. Erosion resistance of liners in most of the RPM pipes is satisfactory but the liner currently used, an isophthalic polyester resin, is questionable. The same resin was used in earlier pipes but with some aluminum silicate added to increase erosion resistance. The filled resin is, however, less flexible than the unfilled material and, thus, may be subject to cracking at lower deflections.

Thermoplastic pipes were found to have good erosion resistance, particularly the polyethylene, although PVC and ABS also were satisfactory.

TEST PROCEDURES

In previous test series, most of the test specimens were laboratory prepared by lining 200-mm (8-in) diameter steel pipe sections. In this series, only a few of the test specimens were lined steel pipe, and none were laboratory prepared.

Figure 1A shows one erosion test apparatus in operation; it is suitable for use only with 200 mm diameter steel specimens. Larger diameter specimens are rotated on motor-driven rollers. Figure 1B is a view of a test specimen also showing constituents of the erosive charges.

After thicknesses and weights of the pipe lining have been established, the erosive charge is introduced into the specimen, the ends sealed, and rotation about the longitudinal axis is begun. The apparatus is a modification of one developed by the Los Angeles Department of Water and Power [5].

The conditions described in table 1 were used for most of the specimens tested. In cooperation with industry, a less time-consuming procedure was developed wherein only a single erosion run was made using No. 4 aggregate and water. The duration of the run was extended to 18 days, it having been found that the extra 4 days would produce the same amount of erosive wear as the three fine sand runs. The procedure was intended for use on RPM pipes but seems adaptable to other lining materials as well. It is particularly useful on larger diameter pipe where run time is directly proportional to diameter; where a 200 mm diameter pipe can be run in 18 days, 54 days are needed to complete a run on 600 mm (24-in.) diameter pipe.

Table 1. — *Test conditions to determine erosion resistance of pipe lining materials*

Run	Velocity		Duration		Erosive charge
	r/min	ft/s	Days	Revolutions	
1	33	1.1	14	660,000	Sand
2	33	1.1	14	660,000	Sand
3	95	3.4	5	660,000	Sand
4	33	1.1	14	660,000	Gravel

After each run, linings are visually checked for damage, weight and thickness changes are determined, and a new charge is placed in the specimen before the next run is started.

The erosive charge described as "sand" consists of 0.34 kg (0.75 lb) each of Nos. 30, 50, 100, and pan-size Clear Creek sand plus 2000 cm^3 of water. The charge described as "gravel" consists of 1.36 kg (3 lb) of No. 4 aggregate plus 2000 cm^3 of water. The foregoing describes the charge for a 200-mm diameter test specimen. Test specimens larger in diameter than 200 mm have the charge size increased in proportion to the increased diameter of the test specimen.

Clear Creek aggregate was used in the tests. A petrographic analysis of the aggregate indicated the following [6]:

> The gravel, rounded to angular in shape with about 5.6 percent flattened and elongated particles, is composed mainly of granitics with lesser amounts of metamorphics and minor amounts of pegmatite, schists, sandstone, altered volcanics, quartz, and feldspar. The material is physically sound and contains only trace amounts of potentially reactive chert particles in the No. 4 sieve size.
>
> The sand, angular to subangular in shape, is composed of the same rock types found in the gravel plus increasing amounts of monomineralic grains of quartz, feldspar, micas, amphiboles, epidote, magnetite, garnet, trace amount of chert, and a few miscellaneous detrital minerals in the finer sizes. The sand is physically sound and contains only trace amounts of potentially alkali-reactive chert.

Mass changes were measured using a 5-kilogram-capacity scale. Thickness changes of linings for steel pipe were measured with the General Electric thickness gage. Thickness measurements were made on 20 spots on the lining and, from the average of these readings, the thickness loss was computed. For the fiberglass-reinforced, polyester-mortar pipes, the asbestos-cement pipe, and the thermoplastic pipes, somewhat different techniques were employed. Either a dial gage caliper or a depth gage-bridge combination was used to determine thickness losses, and a 40-power Bausch and Lomb shop microscope equipped with a scale plate was used to measure original liner thickness, if it was identifiable. If, as in the case of a thermoplastic pipe, no lining was apparent, losses were calculated on the basis of a 1.5-mm (60-mil) thick liner; this is the same as the arbitrary figure used for RPM pipe if the lining was greater than 1.5 mm. If a lining thickness could be established, that value was used up to 1.5 mm, but no lining was considered to be thicker than 1.5 mm for purposes of calculation.

TEST RESULTS

Weight and thickness losses of the linings in the pipe erosion tests are shown in table 2, together with a performance rating for each lining based on a rating system developed in earlier test series. A second system, essentially a "pass-fail" rating using a formula developed for linings for glass-fiber-reinforced pipes, wherein a loss less than 50 percent of the lining thickness in excess of 250 μm (10 mils) is considered satisfactory. Test results from previous studies are included for informational purposes (tables 3 through 6).

Figure 2 shows the action of the erosive charge at the two test speeds during rotation. As may be noted from the two photographs, the erosive charge appears to be moving more slowly at the ends of the cylinder than in the center. This is borne out in the thickness measurements, where losses at the ends were invariably less than in the center of the specimen. Figures 3 through 36 show all of the pipes before and after testing.

Tests on linings are grouped according to lining or, in some cases, pipe type. Figures 2 and 3 show sheet rubber linings for steel pipe, none of which were noticeably or measurably damaged in the tests.

Losses in two kinds of concrete pipe are shown in figure 5. Abrasion resistant aggregate was used in the concrete from which one pipe was made and regular aggregate in the other pipe. Erosion losses were slightly greater (260 μm versus 180 μm [10.2 mils versus 7.2 mils]) in the pipe where regular aggregate was used in making the concrete.

Similarly, erosion losses are compared in abrasion-resistant and ASTM A36 steel pipe in table 7 and shown in figure 6. For further comparison, steel pipe and stainless steel liner losses are included in the table; these latter pipes were run earlier. There is a slightly greater loss in the A36 pipe (30 μm versus 20 μm [1.2 mils versus 0.9 mil]) than in the abrasion-resistant pipe, but the losses are quite small in either and compare with earlier tests.

In table 8, the effectiveness of a thin vinyl resin liner is compared with an epoxy liner and a pipe tested earlier. All of the pipes in this group were made from asbestos cement. All of these pipes, before and after testing, are shown in figures 7, 8, and 9. The vinyl resin liners were not erosion resistant, and were permeable to water.

In table 9, two epoxy and two polyester-resin, glass-reinforced pipes are compared with each other and with similar pipe tested earlier. Figures 10, 11, and 12 show the pipe tested in this series. Polyester resin pipes were found to have better erosion resistance than the epoxy pipes.

Three kinds of thermoplastic pipe are listed in table 10. Polyethylene pipe was most erosion resistant, followed by PVC and ABS. Losses in all three were quite small. Figures 13 and 14 show pipe before and after testing.

Twenty-one RPM pipes are listed in table 11. Sizes ranged from 200- to 600-mm (8- to 24-in) inside diameter and included two steel pipes containing the same polyester resin composition used in RPM pipe linings. Five different liner materials were included: aluminum-silicate-filled polyester resin, polyester-resin-rich mortar, sand and random glass-fiber-filled polyester resin, unfilled bisphenol polyester resin, and unfilled isphthalic polyester resin. The bisphenol resin liner was most erosion resistant, followed by resin-rich mortar, aluminum-silicate-filled polyester, sand and random glass-fiber-filled polyester, and unfilled isophthalic polyester. The average loss was 170 μm (6.7 mils) for all liners studied. RPM pipes before and after testing are shown in figures 15 through 24.

Table 12 lists five RPM pipes having damaged areas that were repaired with glass cloth-reinforced, aluminum-silicate-filled polyester resin overlays. Two of the pipes also had unrepaired impact-damaged areas on which erosion resistance was checked. Erosion resistance of undamaged areas of these same pipes was described earlier under "Erosion Losses in RPM Pipes." On the average, repair materials were about as erosion resistant as pipes overlaid and did remain intact and bonded. Unpatched damaged areas did not erode any faster than undamaged areas. Repaired and damaged areas before and after testing are shown in figures 25 through 36.

DISCUSSION

An examination of table 2 will show, along with data on erosion losses, two rating systems for lining materials — one in a column headed "Percent Thickness Loss Based on Lining," and the other "Performance Rating." The former was developed in cooperation with three manufacturers to evaluate liners for RPM pipe on a basis which was mutually acceptable and one which seemed to discriminate between satisfactory and unsatisfactory materials essentially on a "pass-fail" basis. Requirements for the "inner surface" of RPM taken from a recent Bureau of Reclamation construction specification containing requirements for "Reinforced Plastic Mortar Pipe" follow:

> *Inner surface.* — The inner surface of each pipe shall be composed of unfilled resin or of resin filled with natural sand or fine filler. Natural sand shall be as specified in subparagraph d. (2) above. Fine filler shall be aluminum silicate or other equally hard material. The inner surfact of the pipe is considered to be a waterproof barrier and an erosion-resistant lining. A thickness of 10 mils is required to provide watertightness, and an excess thickness over 10 mils is required for erosion resistance. The total thickness of the lining to be considered for erosion resistance shall not exceed 60 mils. The thickness and/or composition of the lining shall be such that when tested in accordance with subparagraph (a) below, the erosion loss will not exceed 50 percent of the lining thickness which is in excess of 10 mils.
>
> (a) *Erosion-resistance test.* — The contractor shall furnish, at no additional cost to the Government, three test specimens from the initial production run for an erosion-resistance test. Three additional specimens shall be furnished after any change in the inner surface materials or design. The samples shall be sent to the Bureau of Reclamation, Engineering and Research Center, Denver Federal Center, P.O. Box 25007, Denver, Colorado 80225, Attention: Code D-1520.
>
> An erosive charge, consisting of No. 4 (0.185- to 0.375-inch) aggregate and water, shall be introduced into a test specimen of pipe fitted with suitable bulkheads to contain the charge. The length of the specimen shall be 12 inches. The erosive charge shall consist of 4.5 pounds of aggregate and 3,000 cubic centimeters of water. After the erosive charge is introduced, the pipe shall be rotated about its longitudinal axis for 820,000 revolutions at a rate such that the tangential velocity of the inner surface is 1.1 feet per second.
>
> (b) *Determination of erosion resistance.* — Erosion loss shall be determined by measuring the wall thickness at 10 spots equally spaced on each of two longitudinal lines along the pipe before the test is started and by measuring the wall thickness at the same 20 spots after the test is completed. The average loss in thickness for the 20 spots is considered to be the erosion loss. The erosion loss in percent of the lining thickness in excess of 10 mils shall be calculated by the following formula:
>
> $$\text{Percent} = \frac{A}{B\text{-}10}(100)$$
>
> where A = erosion loss in mils
> B = original total lining thickness in mils, not to exceed 60 mils

An explanation of the "Performance Rating" system is shown in footnote 4 on table 2. A comparison of these two systems reveals that lining materials rated "Good" lose less than 26.5 percent in the "Percent Thickness" system, that "Moderate" materials lose between 30 percent and 67 percent, and that those rated "Low" lose 100 percent of the lining.

Quite a large number of the pipes in this test series were RPM pipe, and losses among these varied widely. There was even quite a variation in those claimed to have the same lining material: the liner now used, a clear isophthalic resin, was found to be satisfactory in one case, unsatisfactory in another. Thickness losses in both were nearly the same, but since lining thicknesses were different, the thicker lining was satisfactory, and the thinner lining was unsatisfactory, because of the way in which erosion resistance is determined.

The impact damage repair study showed that repairs were about as erosion resistant as the pipe liner itself and, further, that they bonded well through the course of the erosion test. Claims made for the repairs are that they restore structural integrity to the pipe and prevent water from penetrating to the glass reinforcement. The latter of the two claims, at least, seems to have been verified.

There is a significant difference between the erosion loss in pipe 5U or 5V and pipe AB. Although both are PVC pipe, 5U and 5V were cured by a different process, which may account for the difference in erosion resistance. All of the thermoplastic pipes, especially the polyethylene, have good erosion resistance.

The vinyl lining for asbestos-cement pipe was recommended to provide a barrier between soft water and the pipe. Soft water has been found aggressive to cementitious materials. The vinyl lining in this case was prepared by dissolving a vinyl resin in perchlorethylene in the ratio of 70 percent solvent to 30 percent resin. The membrane formed by this process was found to be low in erosion resistance and, judging from the absorption of water, of dubious value as a barrier. Tests on these linings are covered more extensively in Applied Sciences Referral Memorandum No. 80-1-1 [7].

Evaluation of the concrete pipes CDH-A1 and CDH-A2 and the steel pipes CDH-1 and CDH-2 was requested by the Colorado Department of Highways to provide information needed for selecting a pipe for use in erosive conditions. The data from the test indicate the steel

in pipe CDH-1 is somewhat more erosion resistant than the steel in pipe CDH-2. Similarly, the concrete in pipe CDH-A1 is somewhat more erosion resistant than the concrete in pipe CDH-A2. Also, on the average, the steel is several times more erosion resistant than the concrete. Based on these test results, 25mm (1 inch) of steel might be equal in erosion resistance 200 mm (8 inches) of concrete. Actual service conditions would, of course, have an effect on the relative durabilities of concrete and steel surfaces.

In making these studies, it was intended to establish a test that would give results indicative of the relative performance of lining materials under actual field conditions in which erosion was encountered due to silt- and sand-laden water. Some field observations tend to confirm that the test method does reproduce erosion of the same fundamental character as is found in these particular field exposures. The arbitrary rating systems used to classify the erosion resistance of coatings appears to reflect satisfactorily their relative performance. For instance, coal-tar enamel is generally considered to have good erosion resistance, and this was found to be so in the first test series [1]; vinyl resin paints are generally only moderately erosion resistant in service and were found to be the same in the erosion tests; and phenolic resin red lead priming paint has shown poor erosion resistance in field exposures as well as in these tests.

No attempt was made to relate quantitatively the test results to the rate of erosion which occurs under field conditions. Many variables in a given exposure would affect any numerical factor which might be derived, and little success has been obtained in the past with such direct relationships. It was found previously that the rate of erosion of the coal-tar enamel lining in the Little Thompson Siphon, Colorado-Big Thompson Project, roughly approximated the erosion rate in the laboratory test. Baffle boards were later installed upstream from the inlet to the siphon and these, no doubt, reduced the erosion rate by trapping much of the erosive material.

The data obtained in these tests will add to our information regarding a particular phase of materials characteristics. Generally speaking, our coating selections will continue to be made on the basis of many factors, of which erosion is only one. Known field experiences will, of course, be a major factor in influencing these decisions. Erosion is a problem but, in most cases, not a significant one. The presently specified coatings and materials are satisfactory for a majority of the exposures but, for severely erosive conditions, a material of maximum resistance, as indicated by pipe erosion tests, should be considered.

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Table 2. — *Results of tests on pipe erosion specimens*

Pipe No.	Pipe material[1]	Nominal inside diameter (inches)	Inner surface or liner composition	Lining thickness (mils)	Total losses				Percent thickness loss based on lining (60 mil max.) RPM spec. criterion[3]	Performance rating[4]	Pipe No.
					Weight (percent)[2]	Weight (grams)	Thickness (percent)	Thickness (mils)			
5L	Steel	8	Butyl rubber sheet	250	0.2	3.5	—	[5]0.7	1.4	Good	5L
5M	Steel	8	Neoprene rubber sheet	188	.3	4.0	—	[5] .6	1.2	Good	5M
5N	Steel	8	Natural rubber sheet	125	.6	4.0	—	[5] .7	1.4	Good	5N
5P	RPM	18	Polyester-resin-rich mortar	45	7.2	62.0	16.0	7.2	20.6	Good	5P
5Q	RPM	18	Al_2SiO_3-filled polyester resin	50	9.6	106.0	16.8	8.2	20.5	Good	5Q
5S	Steel	8	Al_2SiO_3-filled polyester resin	110	3.6	40.0	4.4	6.8	13.6	Good	5S
5T	Steel	8	Al_2SiO_3-filled polyester resin	116	4.4	40.0	3.2	4.8	9.6	Good	5T
5U	Nylon-yarn-reinforced PVC	8	PVC	—	—	17.0	—	[5]3.6	7.2	Good	5U
5V	Nylon-yarn-reinforced PVC	8	PVC	—	—	16.0	—	[5]3.4	6.8	Good	5V
5X	RPM	8	Al_2SiO_3-filled polyester resin	25	75.6	106.0	78.4	19.5	100.0	Low	5X
5Y	RPM	8	Polyester-resin-rich mortar	25	28.4	38.0	16.0	3.9	26.0	Good	5Y
5Z	RPM	8	Al_2SiO_3-filled polyester resin	25	76.4	107.0	76.8	19.2	100.0	Low	5Z
6A	RPM	18	Polyester-resin-rich mortar	30	10.8	67.0	24.0	7.4	37.0	Moderate	6A
6B	RPM	18	Al_2SiO_3-filled polyester resin	30	16.4	99.0	9.2	2.5	13.5	Good	6B
6C	RPM	18	Al_2SiO_3-filled polyester resin	30	19.6	107.0	9.2	2.7	13.5	Good	6C
6D	Polyethylene ASTM F678	8	Polyethylene	—	—	3.0	—	[5] .6	1.2	Good	6D
18531A-	RPM	24	Al_2SiO_3-filled polyester (Ashland) resin	30	13.7	124.0	10.0	3.0	15.0	Good	18531A
18531B-	RPM	24	Al_2SiO_3-filled polyester (Ashland) resin	30	14.8	133.0	8.9	2.6	13.0	Good	18531B
71676-	RPM	12	Al_2SiO_3-filled polyester (Ashland) resin	30	13.3	60.0	17.3	5.2	26.0	Good	71676
90876-	RPM	24	Al_2SiO_3-filled polyester (Ashland) resin	30	16.0	144.0	17.7	5.3	26.5	Good	90876
D	Steel	8	Coal-tar enamel	95	11.2	66.0	21.6	20.6	41.2	Good	D

[1] "RPM" = Reinforced plastic mortar pipe.
[2] Based on entire lining.
[3] Calculation: Percent loss = A ÷ (B-10), where A = erosion loss in mils; B = original lining thickness in mils, not to exceed 60 mils; less than 50 percent loss is considered satisfactory.
[4] Rating system: *"Good"* — Good erosion resistance; includes linings losing 20 percent or less in thickness, no wear through liner.
"Moderate" — Moderate erosion resistance; includes linings losing 20 to 80 percent in thickness, less than 10 percent wear through.
"Low" — Low erosion resistance; includes linings losing more than 80 percent in thickness, more than 10 percent wear through.
[5] Thickness loss calculated from weight loss.
[6] Weight loss due to erosion of liner obscured by absorption of water into pipe wall.
[7] No erosion test on these sections; there was only water in the rotating pipe to ascertain integrity of the liner.

Table 3. — *Losses in pipe and Taber Abraser specimens (from report No. P-66)*

Pipe	Lining material	Average per run							Total					
		Pipe specimens 1/				Taber specimens			Pipe specimens				Taber specimens		
		Weight, percent	Weight, grams	Thickness, percent	Thickness, mils	Weight, grams	Thickness, percent	Thickness, mils	Weight, percent	Weight, grams	Thickness, percent	Thickness, mils	Weight, grams	Thickness, percent	Thickness, mils
A	Neoprene, brush applied	3.6	5.2	2.9	0.60	0.099	9.3	1.35	14.5	22.0	11.5	2.5	0.292	33.8	4.9
B	Vinyl resin paint, VR-3	2/ 10.6	3.4	31.4	1.10	--	15.0	0.75	10.6	3.4	31.4	1.1	--	45.0	2.25
C	Phenolic red-lead paint, TT-P-86a (IV)	2/ 90.0	66.0	92.7	3.80	0.140	25.0	1.20	100.0	66.0	92.7	3.8	0.399	63.6	2.8
D	Coal-tar enamel	2.8	16.5	5.4	5.10	--	6.1	5.62	11.2	66.0	21.6	20.6	--	34.1	31.5
E	Cold-applied coal-tar paint, CA-50	2/ 16.4	28.0	22.3	5.20	0.109	8.4	1.80	65.7	112.0	89.5	21.0	0.282	27.9	6.0
F	Epoxy resin base paint	2/ 20.1	8.6	23.0	0.90	0.029	8.3	1.00	60.4	26.0	69.1	3.5	0.198	41.7	5.0
G	Red-lead vinyl resin paint	2/ 15.7	14.0	26.3	1.40	0.086	7.6	0.80	62.9	56.0	79.0	5.8	0.370	35.2	3.7
H	Vinyl resin paint, VR-6	2/ 11.4	13.5	13.5	1.80	--	6.3	0.75	45.8	54.0	54.1	7.2	--	18.7	2.25
I	Pipeline asphalt enamel	1.0	3.9	1.5	1.60	--	4.8	4.30	4.0	15.5	6.2	4.9	--	15.2	13.5
J	Catalyzed phenolic resin paint	1.3	4.8	0.7	0.30	0.06	1.4	1.00	5.2	17.0	3.0	1.2	0.101	5.8	4.0
K	Water emulsion coal-tar paint	2/ 23.7	36.0	32.1	4.50	0.139	10.3	1.80	71.0	108.0	96.2	18.0	0.538	38.3	6.7
L	Cement mortar	0.49	7.5	2.5	4.70	--	--	--	1.9	30.0	10.0	18.8	--	--	--
M	Epoxy resin modified coal-tar paint	2/ 16.4	20.9	22.0	6.80	--	4.2	0.78	49.1	83.5	66.2	20.5	--	18.9	3.5
N	High penetration asphalt	0.0	0.0	0.0	0.0	--	--	--	0.0	0.0	0.0	0.0	--	--	--
O	Zinc-pigmented inorganic paint	2/ 25.0	14.0	25.0	0.25	0.007	11.4	0.37	100.0	53.0	100.0	1.0	0.023	4.6	0.15

1/Coatings B, C, F, K, and M did not complete all four runs.
2/Coatings eroded through to metal; some steel was therefore eroded.

Table 4. — *Average losses in pipe erosion specimens (from report No. P-79)*

Pipe	Lining material	Average losses per run				Total losses			
		Weight, percent	Weight, grams	Thickness, percent	Thickness, mils	Weight, percent	Weight, grams	Thickness, percent	Thickness, mils
P	Epoxy resin modified coal-tar paint	47.2	29.0	67.2	7.8	47.2	29.0	67.2	7.8
Q	Epoxy resin modified coal-tar paint: with epoxy resin paint seal coat	19.3	15.8	25.0	3.7	77.1	63.0	100.0	14.9
R	Asbestos bonded, asphalt coated, corrugated, galvanized steel pipe	0.0	0.0	--	--	0.0	0.0	--	--
C	Phenolic resin base red-lead priming paint, TT-P-86a, Type IV	29.1	52.5	50.0	3.7	58.2	105.0	100.0	7.4
S	Vinyl resin paint, VR-3, 3 coats	16.4	8.0	33.9	1.8	32.9	16.0	67.9	3.6
T	Vinyl resin paint, VR-6, aluminum seal coats	14.9	17.5	19.3	2.6	59.8	70.0	77.2	10.2
U	Vinyl resin paint, VR-6, white seal coats	21.8	26.8	18.5	2.5	87.3	107.0	73.8	10.1
X	Zinc chromate primer, sand filled; phenolic aluminum paint seal coats 1/	3.1	4.0	10.9	2.1	12.6	16.0	43.7	8.3
Y	Epoxy resin primer	22.1	18.8	25.0	1.9	88.6	75.0	100.0	7.5
S-1	Vinyl resin paint, VR-3, 2 coats, first coat sand filled, applied over eroded VR-3 1/	5.7	6.5	8.9	1.5	23.0	26.0	35.5	6.0
Z	Vinyl resin paint, VR-3, 3 coats, second coat sand filled 1/	5.8	8.8	8.9	1.9	23.2	35.0	35.5	7.7
AA	Vinyl resin paint, VR-3, 3 coats, second coat sand filled 1/	0.9	1.5	1.8	0.4	3.7	6.0	7.0	1.6
BB	Fiberglass-reinforced epoxy resin pipe	2.1	27.1	4.6	7.6	8.4	108.6	16.1	30.4
CC	Neoprene synthetic rubber lining with clorosulfonated polyethylene seal coat	5.6	4.4	7.0	0.8	22.5	17.5	27.9	3.1
DD	Neoprene synthetic rubber paint	0.4	0.4	0.6	0.08	1.5	1.5	2.2	0.3
EE	Epoxy modified phenolic resin paint	17.6	19.5	23.5	3.1	70.6	78.0	93.8	12.2
FF	Hot-applied epoxy resin paint	5.4	12.4	7.7	2.1	21.4	49.5	30.8	8.4
GG	Vinyl resin mastic paint, 2 coats	24.6	30.0	25.0	3.5	98.3	120.0	100.0	13.9
HH	Vinyl resin mastic paint, 2 coats, first coat sand filled, C109 Ottawa sand	25.0	28.0	25.0	3.9	100.0	112.0	100.0	15.6
II	Vinyl resin paint, V-101, 5 coats, third coat sand filled 1/	1.8	3.0	2.7	0.6	7.4	12.0	10.7	2.2
JJ	Vinyl resin paint, V-101, 2 coats, VR-3, 3 coats, second VR-3 coat sand filled 1/	1.1	3.3	2.4	1.0	4.4	13.0	9.5	3.9
KK	Hot-applied polyvinyl cloride-polyvinyl acetate copolymer	4.0	1.0	14.9	1.1	16.1	4.0	59.7	4.6
LL	Hot-applied polyvinyl cloride-polyvinyl acetate copolymer	8.4	2.2	16.8	1.4	33.7	9.0	67.4	5.6
OO	Vinyl resin paint, V-101, 5 coats, third coat sand filled 1/	0.6	1.0	2.0	0.5	2.2	4.0	7.9	2.0
RR	Vinyl resin paint, VR-3, 3 coats, second coat sand filled 1/	3.4	8.0	6.5	1.9	15.6	32.0	26.1	7.7
SS	Vinyl resin paint, V-101, 5 coats, third coat sand filled 1/	1.9	2.8	8.1	2.1	7.6	11.0	32.3	8.4
TT	Coal-tar emulsion with polyvinyl chloride copolymer	25.0	68.3	25.0	10.9	100.0	273.0	100.0	43.4
D	Coal-tar enamel	2.8	16.5	5.4	5.1	11.2	66.0	21.6	20.6

1/ Type and size of sand are shown in Table 4.

Table 5. — *Average losses in pipe erosion specimens (from report No. P-93)*

Pipe No.	Lining Material	Average Losses Per Run: Weight, Percent	Weight, Grams	Thickness, Percent	Thickness, Mils	Total Losses: Weight, Percent	Weight, Grams	Thickness, Percent	Thickness, Mils	Performance Rating 2/	Pipe No.
MM	Epoxy Resin Mortar	1.1	9.8	1.2	0.8	4.5	39.0	4.6	3.2	Good	MM
NN	Epoxy Resin Mortar	1.8	8.8	1.7	1.7	7.0	35.0	6.9	6.9	Good	NN
UU	Epoxy Resin Modified Coal-tar Paint, 3 Coats	19.3	27.5	23.4	5.0	77.3	110.0	93.5	20.0	Low	UU
VV	Epoxy Resin Modified Coal-tar Paint, 1 Coat	13.4	28.2	17.8	5.8	53.6	113.0	71.3	23.4	Moderate	VV
XX	Epoxy Resin Modified Coal-tar Paint	19.6	26.5	22.9	5.1	73.1	106.0	91.5	20.5	Low	XX
YY	Coal-tar Paint, CA-50, 3 Coats, 2nd Coat Sand Filled 1/	1.5	5.2	1.8	0.8	5.9	21.0	7.3	3.2	Good	YY
ZZ	Red Lead Priming Paint, TT-P-86a, Type IV, 4 Coats, 2nd Coat Sand Filled 1/	3.1	9	2.7	0.7	12.5	51.0	9.6	2.7	Good	ZZ
AAA	Red Lead Priming Paint, TT-P-86a, Type IV, 2 Coats, 2nd Coat Sand Filled, Plus 2 Coats of Phenolic, Resin Base Aluminum Paint, TT-V-119, TT-A-468a, Type II, Class B 1/	0.7	1.6	3.0	0.8	2.9	6.5	12.2	3.4	Good	AAA
BBB	Epoxy Resin Modified Coal-tar Paint, 3 Coats, 2nd Coat Sand Filled 1/	4.7	15.0	4.7	2.4	18.9	60.0	18.8	9.7	Good	BBB
CCC	Epoxy Resin--Coal-tar Mortar	0.8	11.0	0.8	2/1.2	3.1	44.0	3.1	4.8	Good	CCC
DDD	Epoxy Resin--Coal-tar Mortar	0.5	8.5	0.5	2/1.3	1.9	34.0	2.0	5.3	Good	DDD
EEE	Epoxy Resin Modified Coal-tar Paint, 3 Coats, 2nd Coat Sand Filled 1/	2.7	7.2	1.2	2/0.5	10.9	29.0	4.6	2.1	Good	EEE
GGG	Epoxy Resin Paint, 3 Coats, 2nd Coat Sand Filled 1/	1.0	1.8	2.0	0.5	4.1	7.0	7.9	1.9	Good	GGG
HHH	No Lining, Steel Pipe	0.1	7.5	0.1	0.3	0.4	30.0	0.4	1.14	----	HHH
III	No Lining, Cement Asbestos Pipe	---	---	1.0	5.2	---	----	3.9	20.8	Good	III
JJJ	Hot Applied Polyvinyl Chloride-Polyvinyl Acetate Copolymer, Factory Applied	11.4	6.2	11.2	1.3	45.5	25.0	45.0	5.1	Moderate	JJJ
KKK	Hot Applied Polyvinyl Chloride--Polyvinyl Acetate Copolymer, Factory Applied	14.3	6.0	14.2	1.2	47.1	24.0	57.6	4.9	Moderate	KKK
LLL	Fiberglass Reinforced Epoxy Resin Pipe with Epoxy Resin Lining	0.6	7.5	1.2	2.2	2.4	30.0	4.8	8.7	Good	LLL
MMM	Hot Applied Epoxy Resin, Factory Applied	13.3	10.1	12.8	1.2	53.3	40.5	53.2	5.0	Low	MMM
NNN	Polyester Resin Reinforced with Chopped Glass Fibers	3.4	11.4	4.9	2.3	13.6	45.5	19.6	8.9	Good	NNN
D	Coal-tar Enamel	2.8	16.5	5.4	5.1	11.2	66.0	21.6	20.6	Good	D

1/ Sand used was 20-30 sieve size Ottowa sand (ASTM C-190)

2/ Rating System: "Good"--Good erosion resistance; includes materials losing 5 percent or less in weight or thickness per run, no wear-through to steel.

"Moderate"--Moderate erosion resistance; includes materials losing 5 to 20 percent in weight or thickness per run, 10 percent or less wear-through to steel.

"Low"--Low erosion resistance; includes materials losing more than 20 percent in weight or thickness per run, more than 10 percent wear-through to steel.

"Poor"--Poor erosion resistance; includes materials partly worn through to steel after only 1 or 2 runs using sand as the erosive medium.

Table 6. — *Average losses in pipe erosion specimens (from report No. ChE-97)*

Pipe No.	Lining Material	Average losses per run				Total losses				Performance rating 1/	Pipe No.
		Weight, percent	Weight, grams	Thickness, percent	Thickness, mils	Weight, percent	Weight, grams	Thickness, percent	Thickness, mils		
3F	Epoxy polysulfide mortar	0.5	8.2	1.0	2.4	9.0	33.0	4.0	9.5	Good	3F
3-O	4 coats of VR-3, top is white	17.2	12.2	17.4	1.3	68.8	49.0	69.6	5.4	Low	3-O
3P	4 coats of VR-3, top is red	13.3	12.0	13.1	1.4	53.2	48.0	52.4	5.5	Moderate	3P
3Q	4 coats of VR-3, top is white	12.7	13.6	15.3	2.0	50.8	54.5	61.2	8.1	Moderate	3Q
3R	4 coats of VR-3, top is white	18.4	15.8	20.2	1.5	73.6	63.5	80.8	6.0	Low	3R
3S	Epoxy resin paint	9.6	20.1	15.1	3.4	38.4	85.0	60.4	13.8	Moderate	3S
3T	Epoxy resin paint	15.3	23.0	18.4	4.0	61.2	92.5	73.6	15.9	Moderate	3T
3U	Neoprene adhesive, 4 coats	0.7	0.5	1.2	0.3	2.7	2.0	4.8	1.2	Good	3U
3V	Blue polyurethane elastomer / Pink polyurethane elastomer	0.6	2.2	0.2 0.5	0.2 0.3	2.5	2.0	0.8 2.0	0.8 1.2	Good / Good	3V
3W	4 coats of neoprene paint	0.6	0.6	0.8	0.1	2.4	2.5	3.2	0.4	Good	3W
3X	4 coats of neoprene paint	16.5	16.5	21.0	3.0	66.0	66.0	84.0	12.1	Low	3X
3Y	Polysulfide rubber coating	25.0	17.0	25.0	1.2	100.0	68.0	100.0	4.6	Low	3Y
3Z	Polyurethane coating	0.3	0.5	0.8	0.2	1.2	1.0	3.2	0.7	Good	3Z
4A	Epoxy resin paint	13.0	13.2	19.0	2.1	52.0	53.0	76.0	8.2	Moderate	4A
4B	Polyurethane potting and molding compound	0.0	0.0	0.3	0.1	0.0	0.0	1.2	0.5	Good	4B
4C	Asbestos-cement pipe with transparent epoxy resin liner	-	5.0	-	-	-	19.0	-	-	Good	4C
4D	Fused vinyl resin	2.6	4.5	4.0	1.3	10.4	18.0	16.0	5.3	Good	4D
4E	Fused epoxy resin	-	15.0	23.0	2.3	-	61.0	98.0	9.3	Poor	4E
4F	Fused epoxy resin	22.5	24.0	25.0	2.3	90.0	97.0	100.0	9.0	Poor	4F
4G	Fused epoxy resin	20.0	20.0	21.0	3.7	80.0	79.0	84.0	14.9	Low	4G
4H	3-coat epoxy resin paint	1.6	6.0	2.1	1.8	6.6	24.0	8.5	7.2	Good	4H
4I	Fused chlorinated polyether	-	4.2	10.1	1.0	-	17.0	40.4	5.8	Poor	4I
4J	Epoxy joint sealer	-	2.2	4.0	2.8	-	9.0	16.0	2.9	-	4J
4K	Coal tar epoxy paint	15.1	43.7	18.2	11.8	60.6	175.0	72.8	35.4	Moderate	4K
4L	Coal tar epoxy paint	21.6	30.5	23.1	4.8	86.5	122.0	92.6	19.1	Low	4L
4M	Polyurethane coating	0.0	Sl. gain	1.0	0.6	0.0	Sl. gain	2.4	4.0	Good	4M
4N	Epoxy resin paint	33.3	20.0	33.3	2.3	100.0	59.0	100.0	7.0	Poor	4N
4-O	Filament wound epoxy pipe - Polyester liner	0.8	9.8	1.4	2.9	3.2	39.0	5.6	11.5	Good	4-O
4P	Ceramic spray coating	3.7	14.2	3.8	3.0	14.8	57.0	15.1	12.2	Good	4P
4Q	Epoxy mortar	-	31.2	0.0	0.0	-	125.0	-	0.0	Good	4Q
4R	Epoxy mortar	-	5.0	1.0	1.0	-	19.0	4.0	4.0	Good	4R
4S	Polyurethane coating	1.9	1.0	2.6	0.6	7.8	4.0	10.3	2.3	Good	4S
4T	Flame sprayed molybdenum metal	-	6.8	13.8	0.4	-	27.0	55.2	1.6	Moderate	4T
4U	Flame sprayed aluminum oxide	-	19.0	22.0	1.2	-	76.0	87.7	5.0	Low	4U
4V	Flame sprayed bronze metal	-	7.3	6.0	1.1	-	29.0	24.2	4.4	Moderate	4V
4W	Flame sprayed stainless steel	-	5.5	3.8	0.4	-	22.0	15.4	1.2	Good	4W
4X	Flame sprayed stainless steel	-	3.6	9.6	0.1	-	14.5	38.6	0.5	Moderate	4X
4Y	Filament wound polyester mortar pipe with polyester resin liner	1.5	2.6	8.8	5.5	6.0	105.0	35.2	22.0	Moderate	4Y
4Z	Filament wound polyester mortar pipe with rubber liner	0.1	2.0	2.0	1.0	0.4	6.5	4.0	4.5	Good	4Z
5A	Filament wound polyester mortar pipe with polyester mortar lining	0.4	6.8	5.6	1.7	1.6	27.0	21.4	6.7	Good	5A
5B	Epoxy mortar	0.2	3.3	0.4	2.0	1.0	13.0	1.8	7.5	Good	5B
5C	Epoxy mortar	1.0	25.2	2.8	10.9	4.0	101.0	11.0	43.5	Good	5C
5D	Epoxy mortar	0.1	1.8	0.8	3.0	0.5	7.0	3.0	12.0	Good	5D
5E	Epoxy mortar	1.4	34.8	3.5	17.2	5.6	139.0	14.0	69.0	Good	5E
5F	Epoxy mortar	11.4	54.0	13.5	20.8	45.5	216.0	54.0	83.0	Moderate	5F
5G	Coal tar enamel	0.1	0.6	0.6	0.6	1.5	9.0	10.0	9.0	Good	5G
5H	Coal tar enamel	0.4	2.0	0.2	0.2	5.0	27.0	2.8	2.5	Good	5H
5I	26-gage Type 304 stainless steel sheet	0.6	2.7	1.2	0.7	2.4	11.0	4.8	1.0	Good	5I
5J	Neoprene-polyurethane elastomer	Sl. gain	Sl. gain	1.0	0.2	Sl. gain	Sl. gain	4.0	1.0	Good	5J
D	Coal tar enamel	2.8	16.5	5.4	5.1	11.2	66.0	21.6	20.6	Good	D

1/ Rating system: "Good" - Good erosion resistance; includes materials losing 5 percent or less in weight or thickness per run, no wear-through to steel.
"Moderate" - Moderate erosion resistance; includes materials losing 5 to 20 percent in weight or thickness per run, 10 percent or less wear-through to steel.
"Low" - Low erosion resistance; includes materials losing more than 20 percent in weight or thickness per run, more than 10 percent wear-through to steel.
"Poor" - Poor erosion resistance; includes materials partly worn through to steel after only one or two runs using sand as the erosive medium.

Table 7. — *Erosion losses in steel pipe*

Pipe No.	Pipe or liner	Initial liner thickness (mils)	Thickness loss		Performance rating
			Percent of liner[1]	mils	
3H	No liner	—	2.2	1.1	Good
5I	Type 304 stainless steel liner	18.7	11.5	1.0	Good
CDH-1	Abrasion-resistant steel pipe — no liner	—	1.8	0.9	Good
CDH-2	A 36 steel pipe — no liner	—	2.4	1.2	Good

[1] Percent thickness loss based on lining thickness of 60 mils maximum, as described in specifications for RPM pipe.

Calculation of percent loss = $\frac{A}{B\text{-}10}$, where A = erosion loss in mils and
B = original thickness of lining in mils.

Table 8. — *Erosion losses in asbestos-cement pipe*

Pipe No.	Pipe or liner	Initial liner thickness (mils)	Thickness loss		Performance rating
			Percent of liner[1]	mils	
3I	No liner	—	—	20.8	Good
4C	Epoxy	40	13	4.0	Good
6M	Vinyl	5	100	16.4	Low
6N	Vinyl	5	100	18.3	Low
6O	Vinyl	5	[2] —	—	—
6P	Vinyl	5	[2] —	—	—

[1] Percent thickness loss based on lining thickness of 60 mils maximum, as described in specifications for RPM pipe.

Calculation of percent loss = $\frac{A}{B\text{-}10}$, where A = erosion loss in mils and
B = original thickness of lining in mils.

[2] No erosion test on these sections; there was only water in the rotating pipe to ascertain integrity of the liner. Pipe 6O gained 79 grams and pipe 6P gained 36 grams during the test, and linings in both pipes developed fine blisters.

Table 9. — *Erosion losses in reinforced thermosetting resin pipe*

Pipe No.	Resin type	Initial liner thickness (mils)	Thickness loss		Performance rating
			Percent of liner[1]	mils	
2B	Epoxy	10	100	30.4	Low
3L	Epoxy	50	22	8.7	Good
[2]3N	Polyester	46	24	8.6	Good
4O	Polyester	60	23	11.5	Good
6F	Epoxy	3	100	5.3	Low
6H	Epoxy	3	100	7.2	Low
6R	Polyester	19.5	67	6.4	Moderate
6S	Polyester	77	16	7.8	Good

[1] Percent thickness loss based on lining thickness of 60 mils, maximum, as described in specifications for RPM pipe.

Calculation of percent loss = $\frac{A}{B\text{-}10}$, where A = erosion loss in mils and
B = original thickness of lining in mils.

[2] Steel pipe with chopped random-glass-reinforced liner.

Table 10. — *Erosion losses in thermoplastic pipe*

Pipe No.	Resin type	Initial liner thickness (mils)	Thickness loss		Performance rating
			Percent of liner[1]	mils	
AB	Polyvinyl chloride	—	2.0	1.0	Good
5U	Polyvinyl chloride	—	7.2	3.6	Good
5V	Polyvinyl chloride	—	6.8	3.4	Good
6D	Polyethylene	—	1.2	0.6	Good
6T	ABS	70	7.4	3.7	Good

[1] Percent thickness loss based on lining thickness of 60 mils maximum, as described in specifications for RPM pipe.

Calculation of percent loss = $\frac{A}{B\text{-}10}$, where A = erosion loss in mils and
B = original thickness of lining in mils.

Table 11. — *Erosion losses in RPM pipe*

Pipe No.	Liner composition	Initial liner thickness (mils)	Thickness loss		Performance rating
			Percent of liner[1]	mils	
[2]5S	Al_2SiO_3-filled polyester resin	110	13.6	6.8	Good
[2]5T	Al_2SiO_3-filled polyester resin	116	9.6	4.8	Good
5P	Polyvinyl-resin-rich mortar	45	20.6	7.2	Good
5Q	Al_2SiO_3-filled polyester resin	50	20.5	8.2	Good
5X	Al_2SiO_3-filled polyester resin	25	100.00	19.5	Low
5Y	Polyester-resin-rich mortar	25	26.0	3.9	Good
5Z	Al_2SiO_3-filled polyester resin	25	100.0	19.2	Low
6A	Polyester-resin-rich mortar	30	37.0	7.4	Moderate
6B	Al_2SiO_3-filled polyester resin	30	13.5	2.5	Good
6C	Al_2SiO_3-filled polyester resin	30	13.5	2.7	Good
6L	Sand and random glass-fiber-filled polyester resin	35	29.6	7.4	Moderate
6M	Al_2SiO_3-filled polyester (Ashland) resin	30	26.0	5.3	Good
6Q	Bisphenol polyester resin (type 2 liner)	45	10.0	3.5	Good
6U	Isophthalic polyester resin (type 1 liner)	30	60.5	12.1	Moderate
6V	Isophthalic polyester resin (type 1 liner)	38	41.4	11.6	Moderate
18380A	Al_2SiO_3-filled polyester (Ashland) resin	20	38.0	3.8	Moderate
18380B	Al_2SiO_3-filled polyester (Ashland) resin	20	38.0	3.8	Moderate
18531A	Al_2SiO_3-filled polyester (Ashland) resin	30	15.0	3.0	Good
18531B	Al_2SiO_3-filled polyester (Ashland) resin	30	13.0	2.6	Good
71676	Al_2SiO_3-filled polyester (Ashland) resin	30	26.0	5.2	Good
90876	Al_2SiO_3-filled polyester (Ashland) resin	30	26.5	5.3	Good

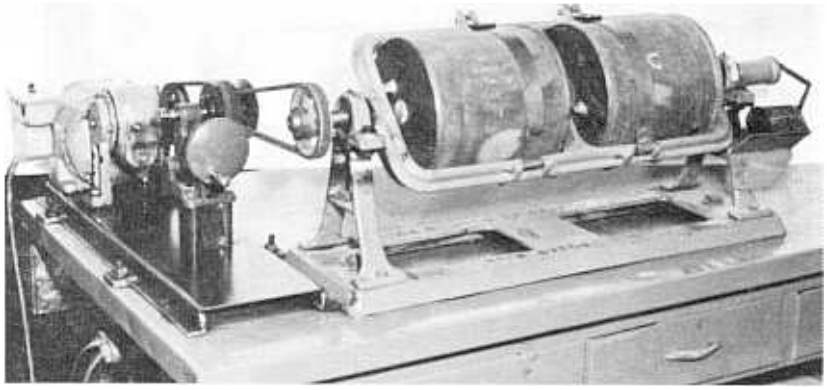
[1] Percent thickness loss based on lining thickness of 60 mils maximum, as described in specifications for RPM pipe.

Calculation of percent loss = $\frac{A}{B\text{-}10}$, where A = erosion loss in mils and
B = original thickness of lining in mils not to exceed 60 mils.

[2] Steel pipe containing RPM lining material.

Table 12. — *Erosion resistance evaluation of RPM pipe having impact damage and repairs*

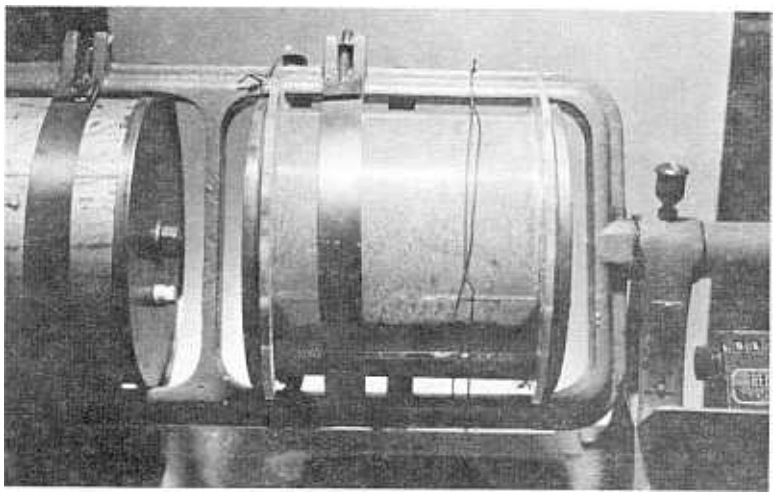
Pipe No.	Liner composition	Repair material	Thickness loss, mils		
			Patched area	Unpatched damaged area	Undamaged area
5Y	Resin-rich mortar	Al_2SiO_3-filled resin and glass cloth	11.0	—	3.9
5Z	Al_2SiO_3-filled resin polyester	Al_2SiO_3-filled resin and glass cloth	9.0	—	19.2
6A	Resin-rich mortar	Al_2SiO_3-filled resin and glass cloth	1.0	0.6	7.4
6B	Al_2SiO_3-filled polyester	Al_2SiO_3-filled resin and glass cloth	1.4	2.8	2.5
6C	Al_2SiO_3-filled polyester	Al_2SiO_3-filled resin	1.5	—	2.7



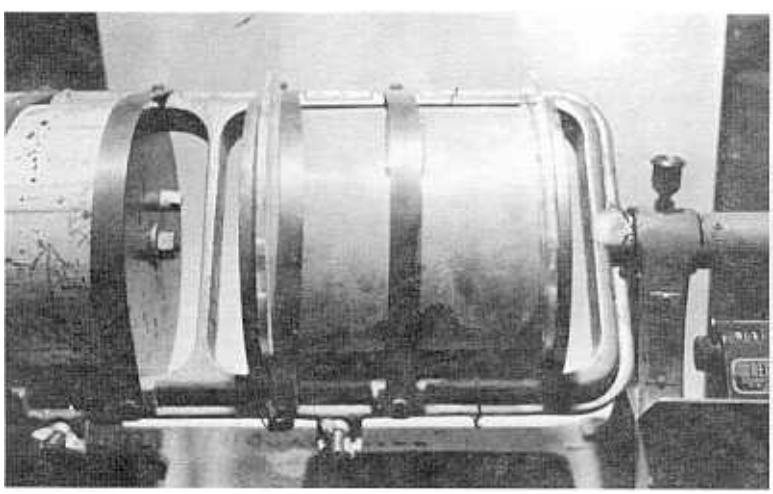
A. Pipe lining erosion test device in operation. Photo P801-D-80638

B. View of a pipe lining test specimen showing end plates, gaskets, pipe, and two types of erosive media used. Photo P801-D-80639

Figure 1. — Views of test apparatus, specimen, and components of erosive charge.

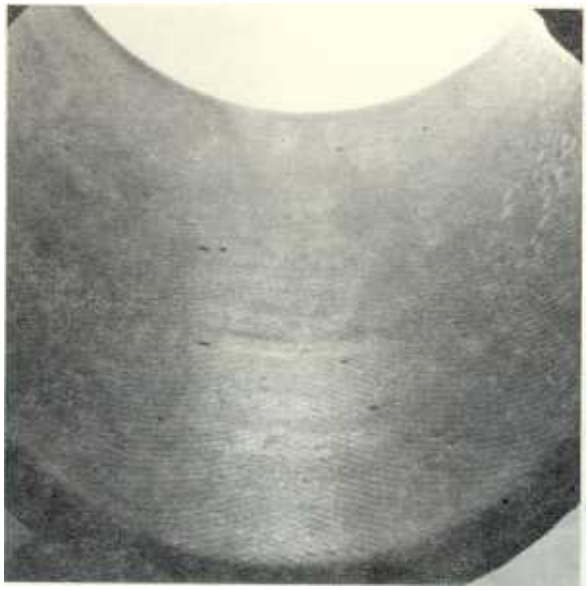


A. Rotation mechanism turning at 33 r/min, using sand as the erosive medium. The clear plastic cylinder was employed so that the action of the charge could be observed. Note how the sand appears to "drag" at the ends of the cylinder. Photo P801-D-80640

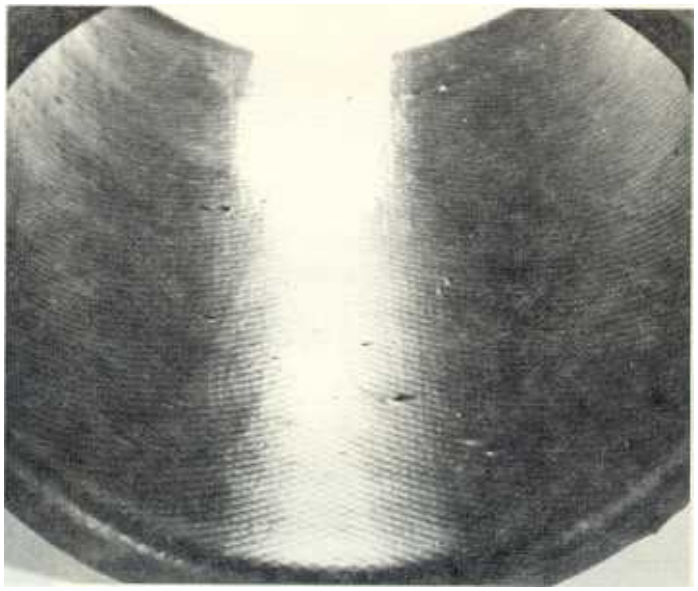


B. Rotation mechanism turning at 95 r/min, using sand as the erosive medium. Again the clear plastic cylinder was employed so that the action of the charge could be observed. The dragging effect is seen to occur at the ends of the pipe and also in the center. Photo P801-D-80641

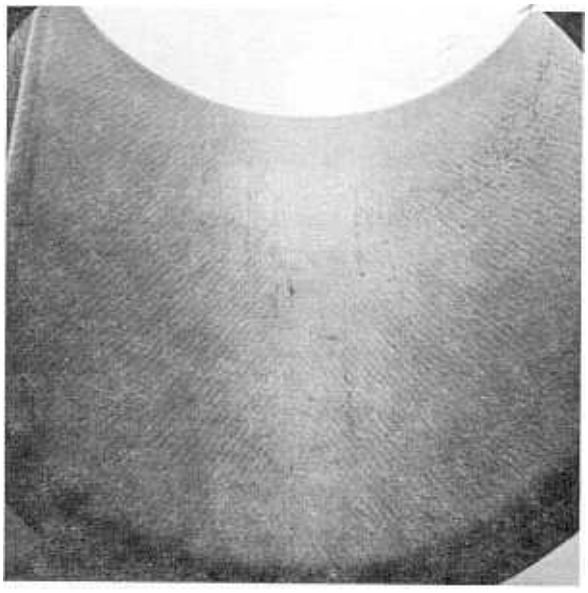
Figure 2. — Rotating mechanism in operation.



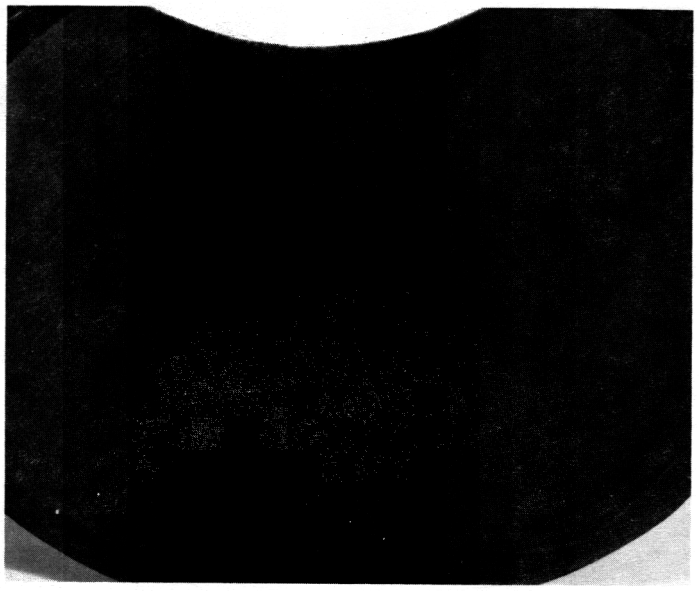
A. Pipe 5L before test. 1/4-inch thick butyl rubber sheet lining. Edges of sheet are belled to cover ends of pipe. Photo P801-D-80642



B. Pipe 5L after test. No observable damage. Erosion resistance is good. Photo P801-D-80643

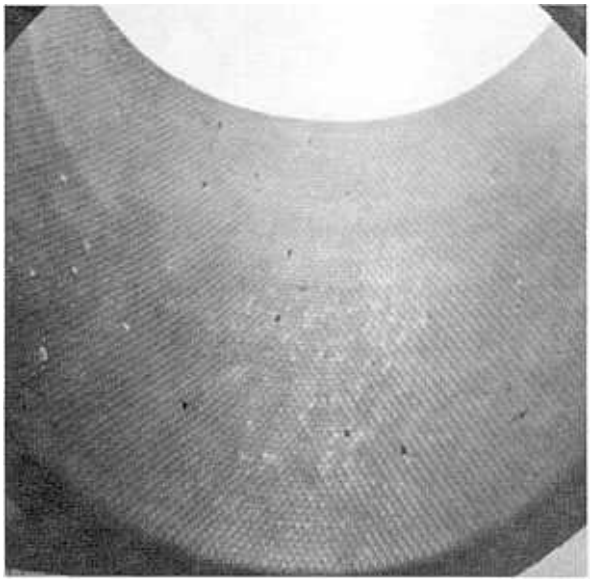


C. Pipe 5M before test. 3/16-inch thick neoprene rubber sheet lining. Edges of sheet are belled to cover ends of pipe. Photo P801-D-80644

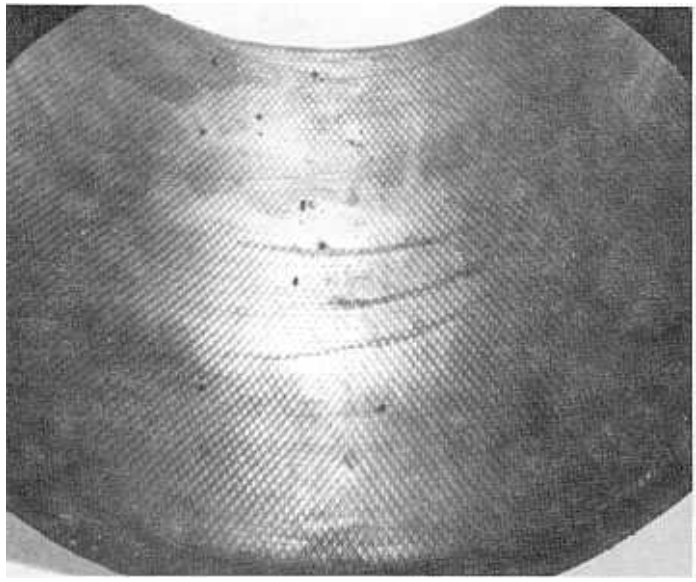


D. Pipe 5M after test. No damage. Erosion resistance is good. Photo P801-D-80645

Figure 3. — Butyl and neoprene sheet rubber linings before and after test.

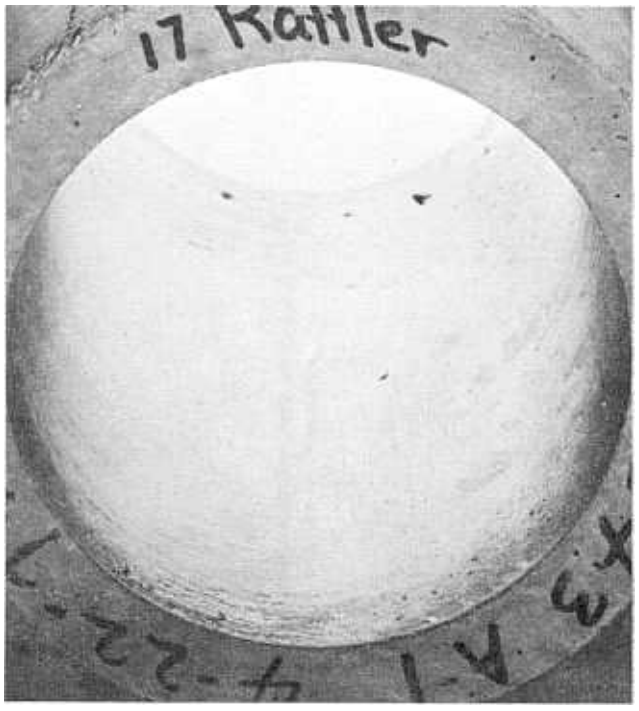


A. Pipe 5N before test. 1/8-inch thick, 35 durometer, natural rubber sheet lining. Edges of sheet are belled to cover ends of pipe. Photo P801-D-80646

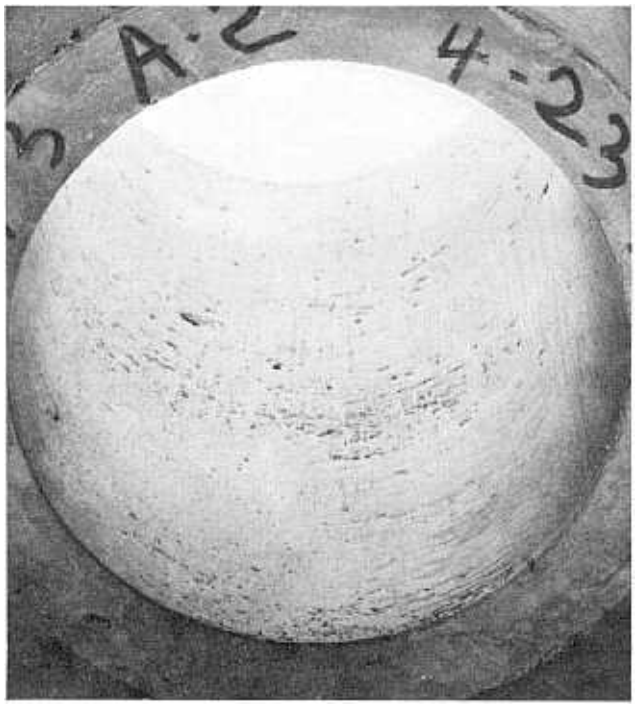


B. Pipe 5N after test. No damage. Erosion resistance is good. Photo P801-D-80647

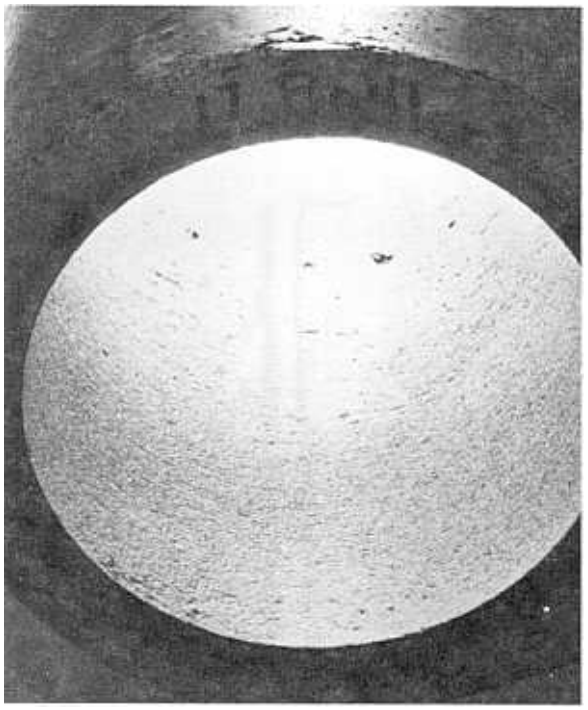
Figure 4. — Natural rubber sheet lining before and after test.



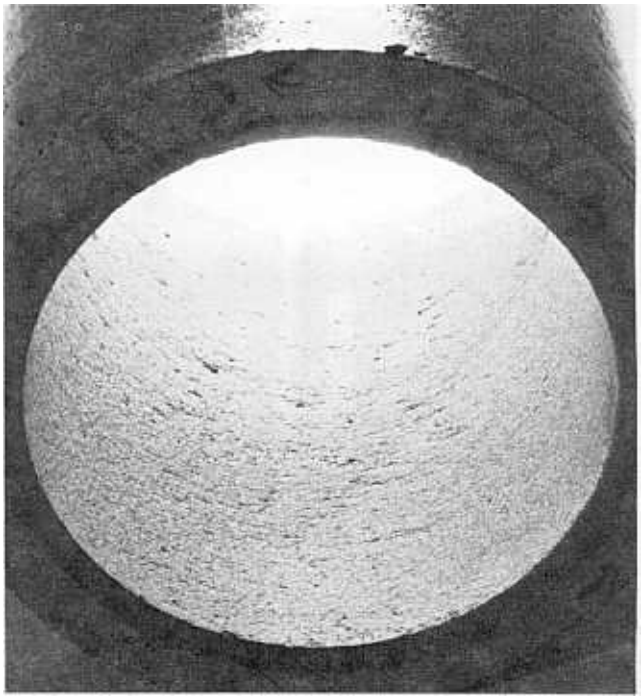
A. Concrete specimen CDH A-1 before test. Concrete contains abrasion resistant aggregate. Photo P801-D-80648



B. Concrete specimen CDH A-2 before test. Regular concrete aggregate. Photo P801-D-80649



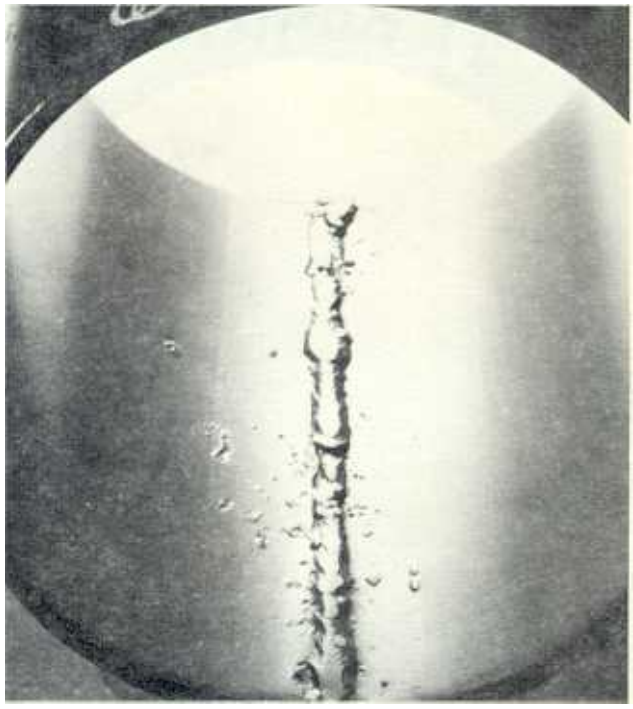
C. Concrete specimen CDH A-1 after test. Thickness loss = 7.2 mils. Erosion resistance is good. Photo P801-D-80650



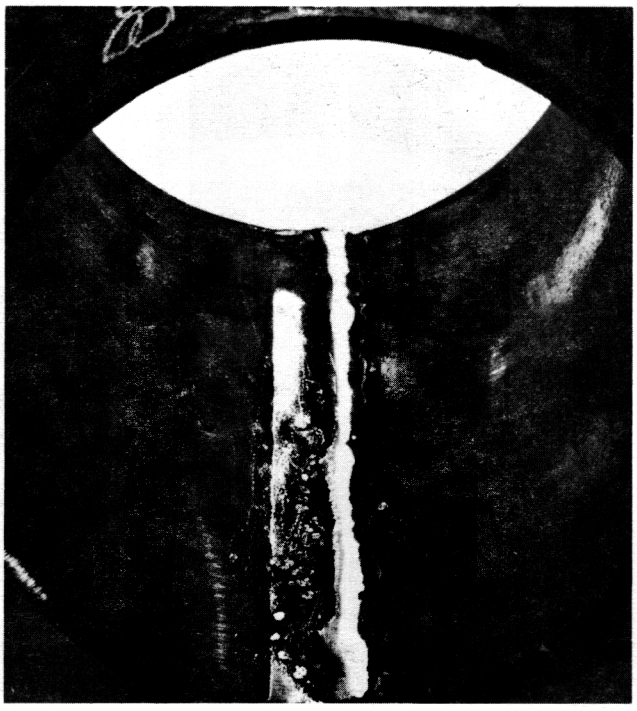
D. Concrete specimen CDH A-2 after test. Thickness loss = 10.2 mils. Erosion resistance is good. Photo P801-D-80651

Figure 5. — Concrete pipe specimens before and after test.

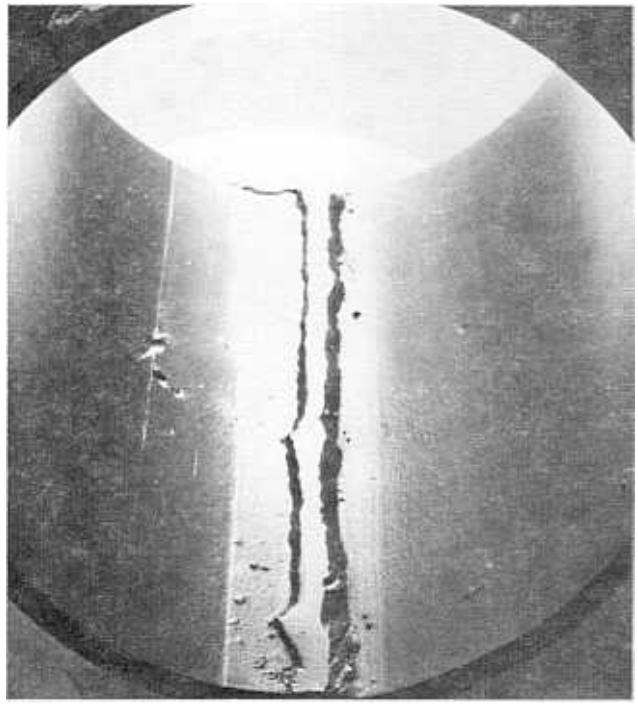
A. Steel pipe CDH-1 before test. Abrasion resistant steel. Photo P801-D-80652



B. Steel pipe CDH-2 before test. ASTM A-36 steel. Photo P801-D-80653



C. Steel pipe CDH-1 after test. Total loss = 0.9 mil; pipe has good erosion resistance. Photo P801-D-80654



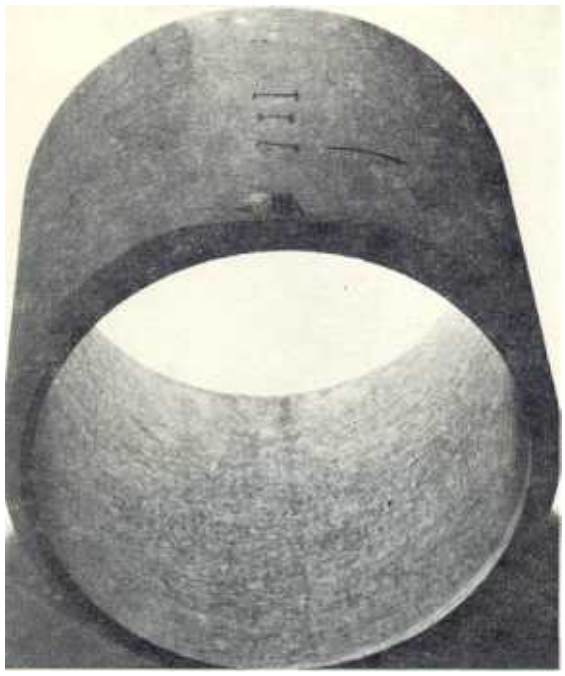
D. Steel pipe CDH-2 after test. Total loss = 1.2 mils; pipe has good erosion resistance. Photo P801-D-80655

Figure 6. — Steel pipe specimens before and after test.

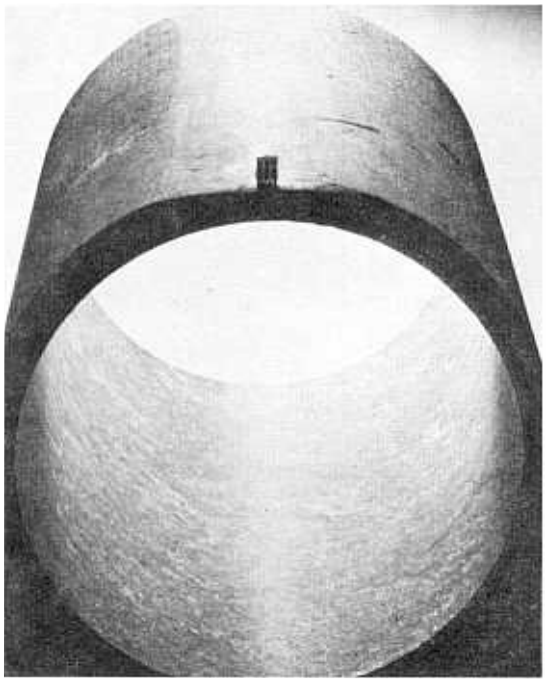
A. Pipe 6M after test. Visible damage is complete removal of liner and wearing away of some of the interior surface of the pipe. Erosion resistance is low. Photo P801-D-80656

B. Pipe 6N after test. Damage in this test section is similar to that for pipe 6M. Erosion resistance is low. Photo P801-D-80657

Figure 7. — Vinyl-resin-lined asbestos-cement pipe after test.

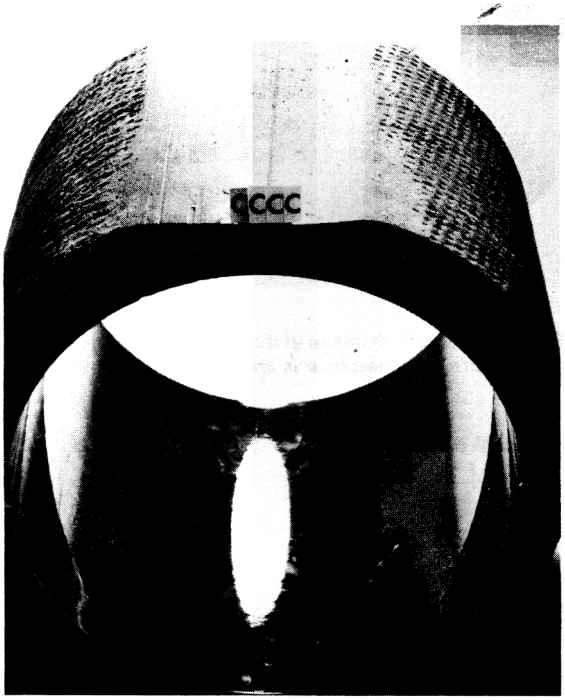


A. Pipe 31 before test. Unlined asbestos-cement pipe. Photo P801-D-80658

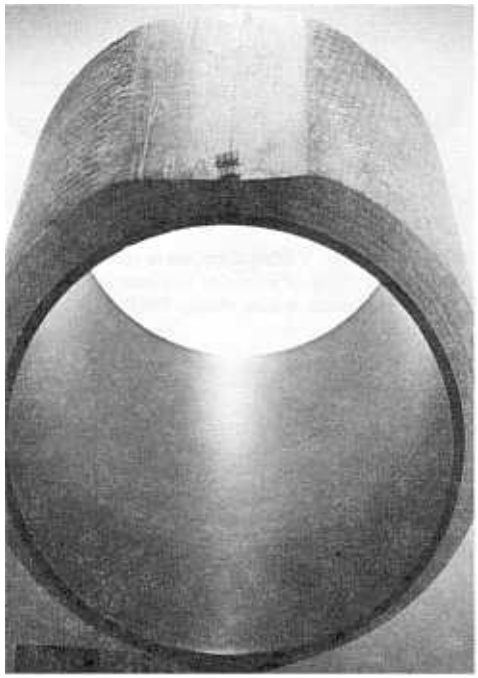


B. Pipe 31 after test. Visible damage is removal of some of the surface. Test run in 1961. Photo P801-D-80659

Figure 8. — Unlined asbestos-cement pipe before and after test.

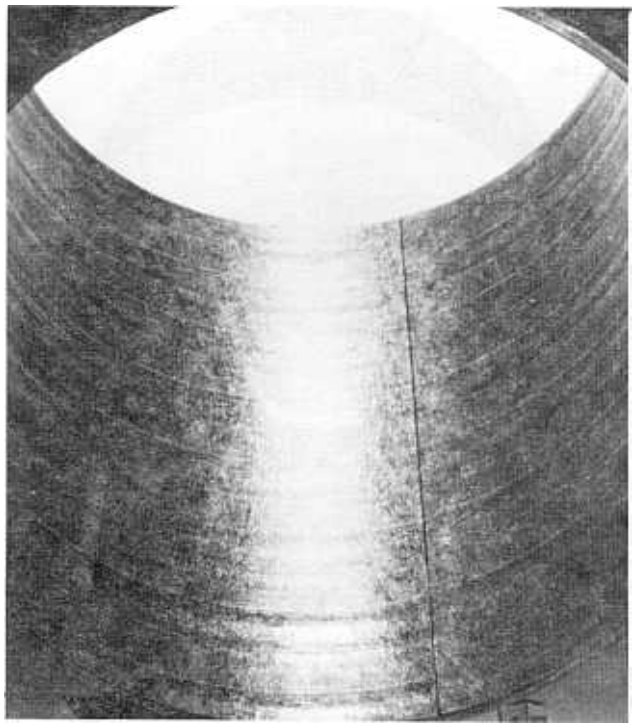


A. Pipe 4C before test. Asbestos cement-pipe with a translucent epoxy resin lining 50 mils thick. Photo P801-D-80660

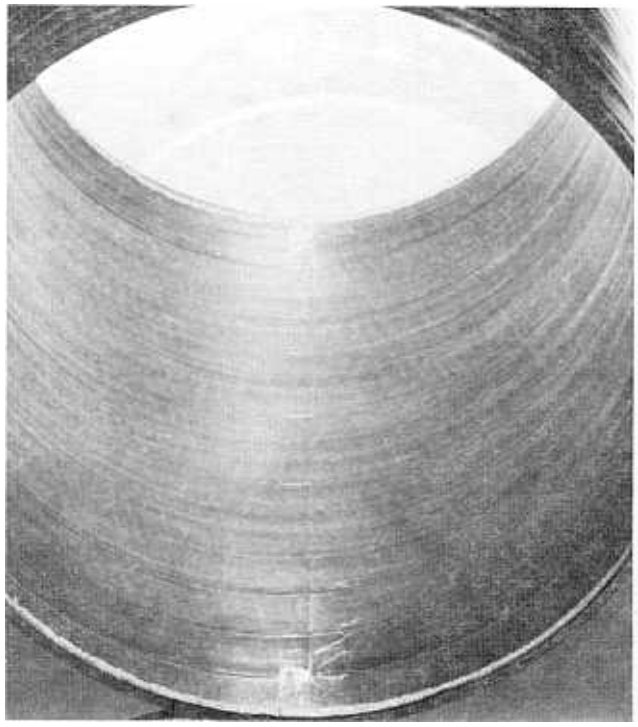


B. Pipe 4C after test. Damage consists of wearing away of about 4 mils of the liner. Test run in 1965. Good erosion resistance. Photo P801-D-80661

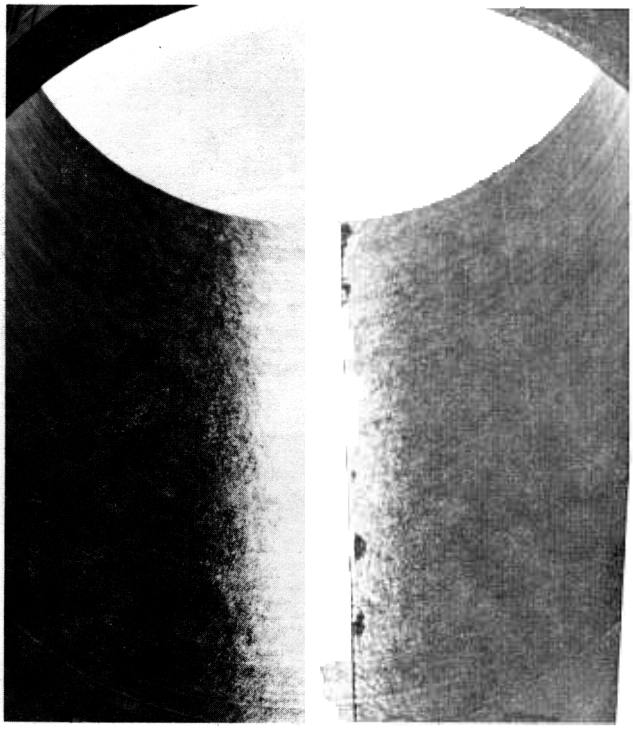
Figure 9. — Epoxy-lined asbestos-cement pipe before and after test.



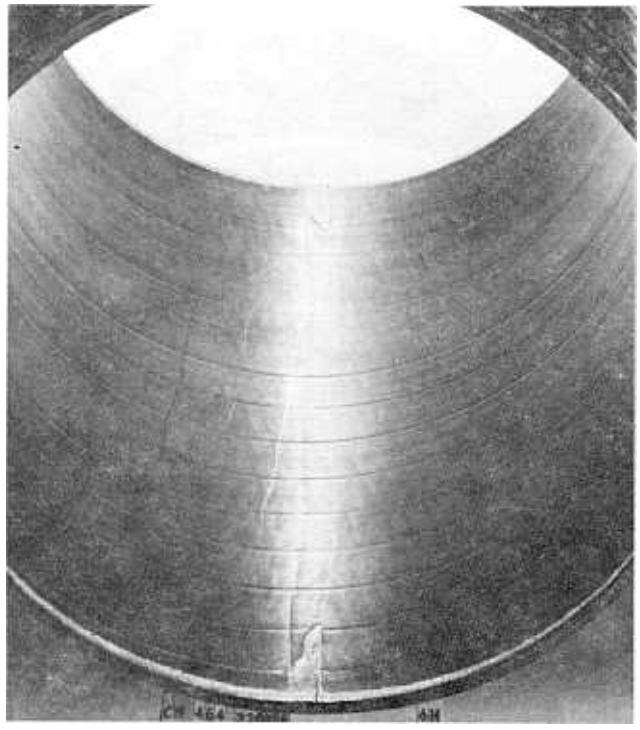
A. Pipe 6F before test. This is a filament-wound-glass reinforced epoxy resin pipe with epoxy mortar core. Photo P801-D-80662



B. Pipe 6F after test. Liner was worn away. Lining has low erosion resistance. Photo P801-D-80663

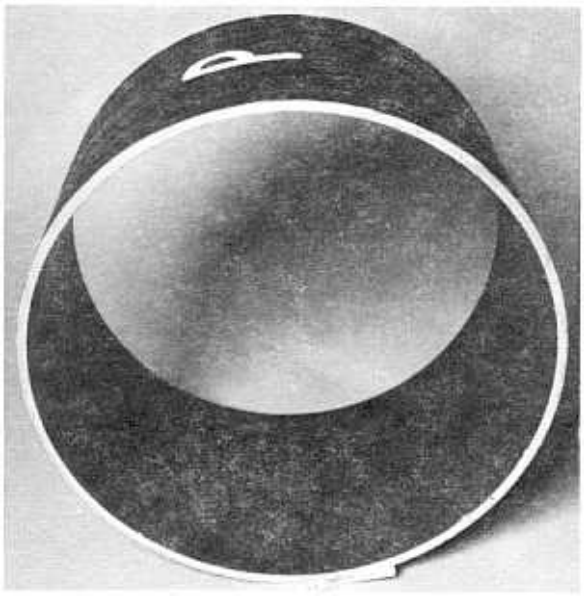


C. Pipe 6H before test. Same pipe composition as pipe 6F. Photo P801-D-80664

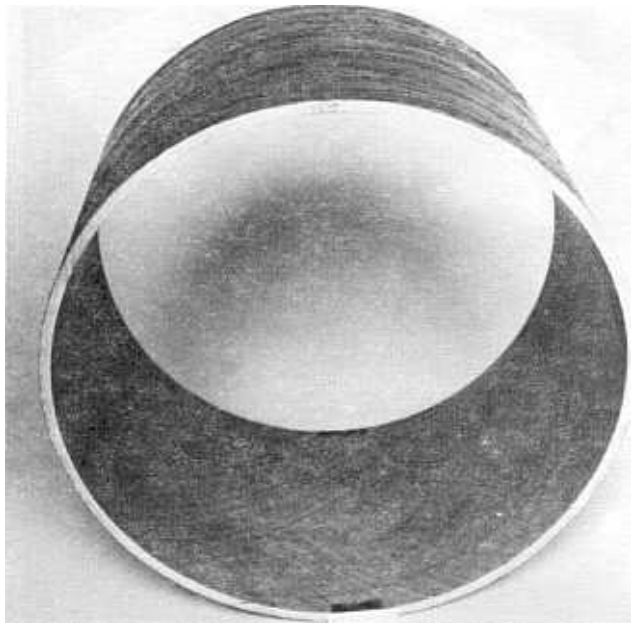


D. Pipe 6H after test. Lining was worn through. Low erosion resistance. Photo P801-D-80665

Figure 10. — Epoxy resin RTRP pipe before and after test.

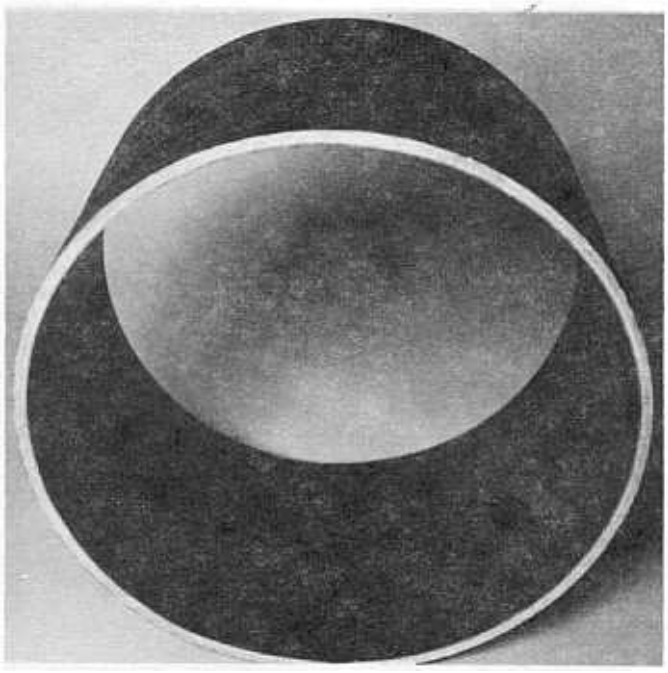


A. Pipe 6R before test. This is a reinforced thermosetting resin pipe (RTRP) manufactured by the filament winding process; the resin used is polyester. The liner is also polyester resin, 20 mils thick. Photo P801-D-80666

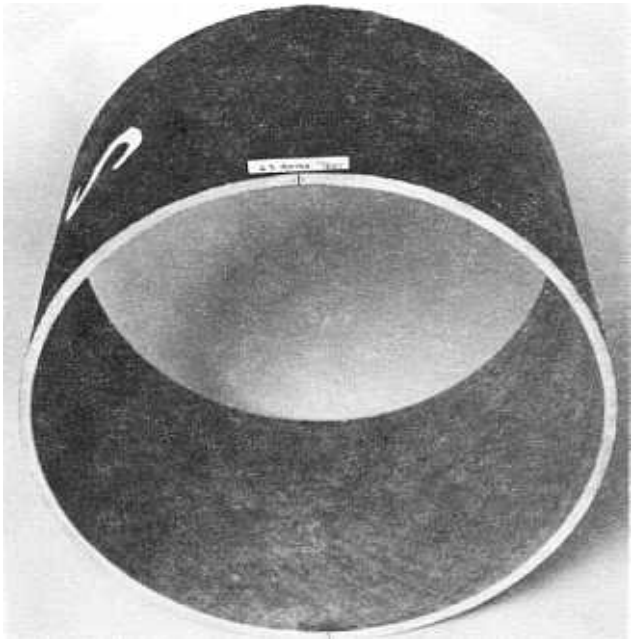


B. Pipe 6R after test. Lining was about 1/3 worn away. Erosion resistance is only moderate. Photo P801-D-80667

Figure 11. — Polyester resin RTRP pipe before and after test.

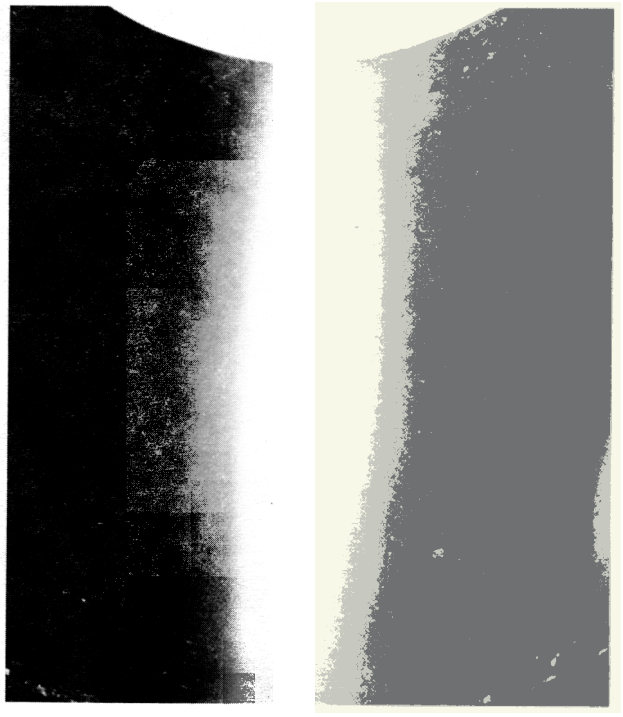


A. Pipe 6S before test. Same type pipe as in figure 11 except the liner is, on the average, 77 mils thick. Photo P801-D-80668



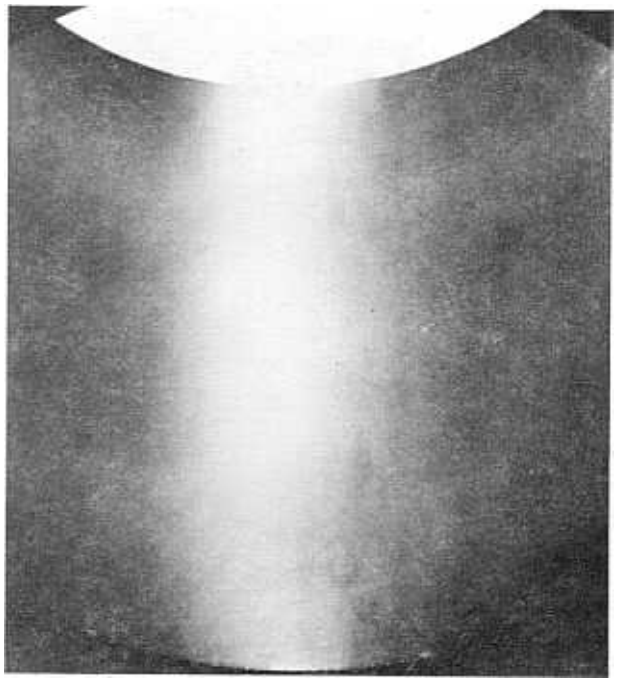
B. Pipe 6S after test. About 10 percent of the lining was worn away. Although the amount of lining worn away was slightly greater than in pipe 6R, erosion resistance is rated good because of the thicker lining. Photo P801-D-80669

Figure 12. — Polyester resin RTRP pipe before and after test.

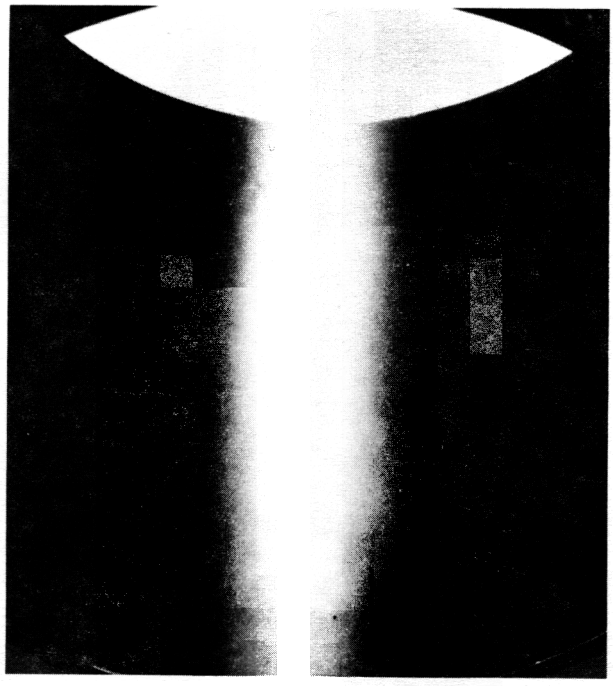


A. Nylon yarn reinforced polyvinyl chloride (PVC) pipe. This is a typical section representing pipes 5U, 5V, and 5W before testing. Photo P801-D-80670

B. Pipe 5V after testing. Main visual effect: slight surface dulling. Good erosion resistance. Photo P801-D-80671

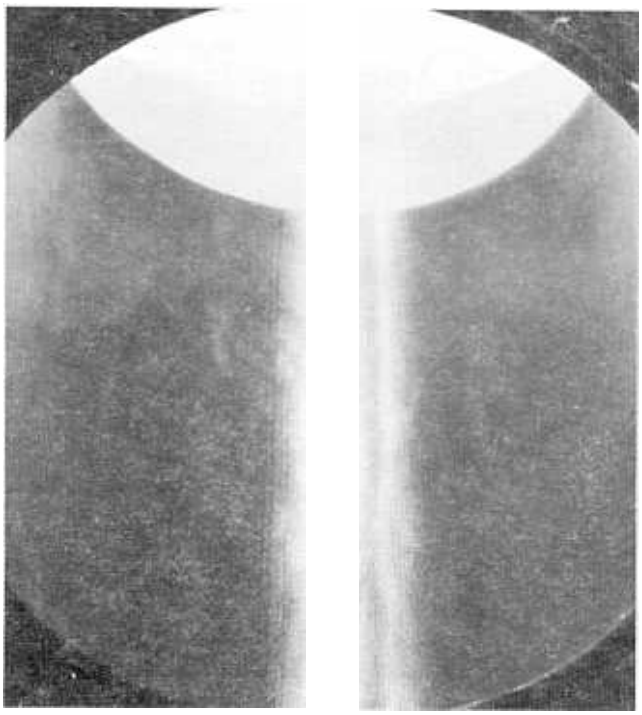


C. Pipe 5U after testing. Main visual effect: slight surface dulling. Good erosion resistance. Photo P801-D-80672

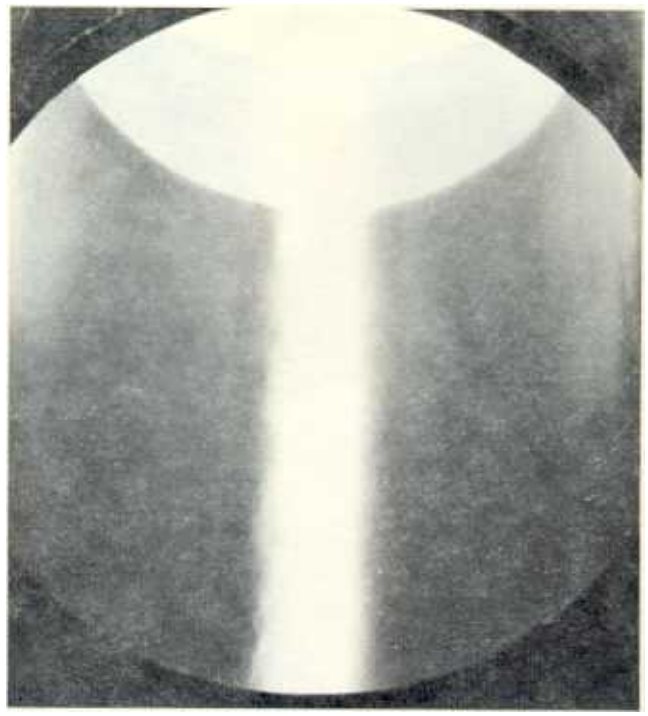


D. Pipe 5W after testing. Water only (no sand); used to determine water absorption and plasticizer migration. Very small weight gain. Photo P801-D-80673

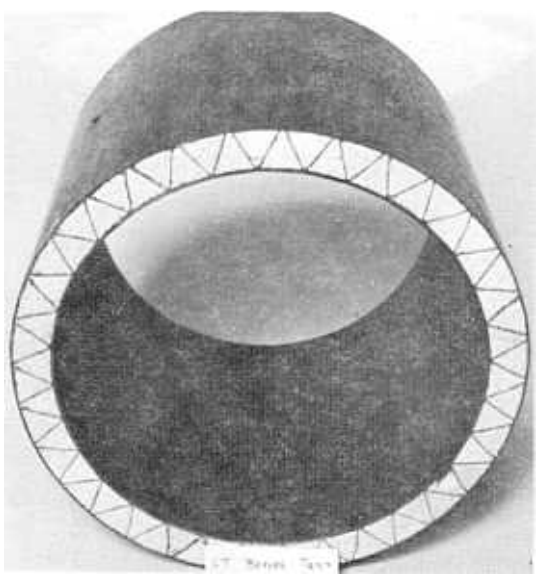
Figure 13. — Nylon-yarn-reinforced PVC pipe before and after test.



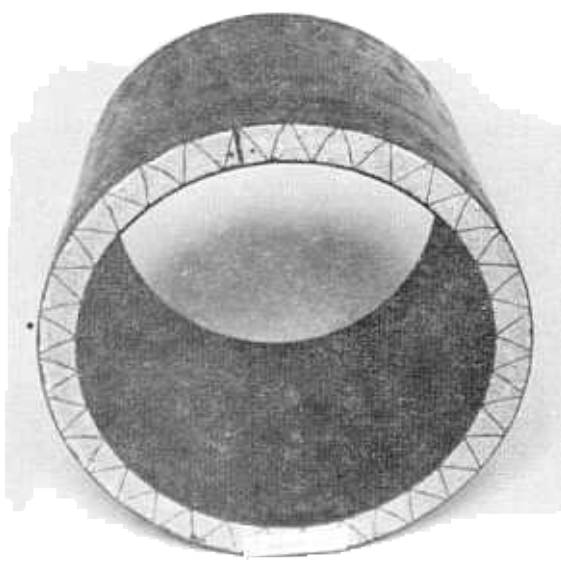
A. Pipe 6D before test. Polyethylene pipe conforming to ASTM F 678. Photo P801-D-80674



B. Pipe 6D after test. No measurable thickness loss. Good erosion resistance. Photo P801-D-80675

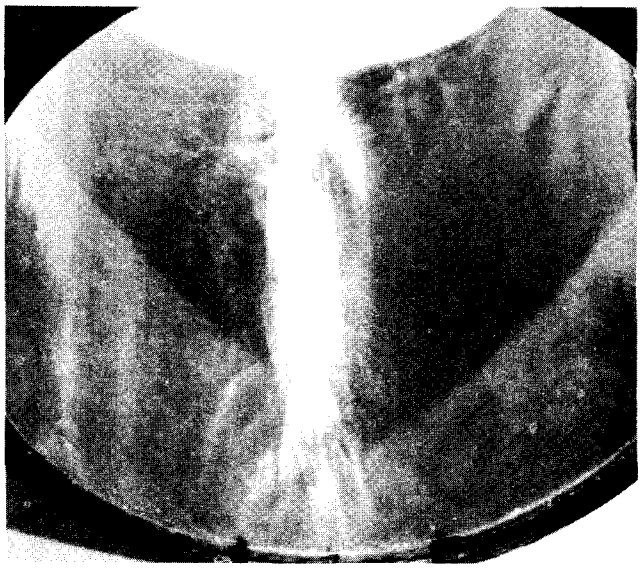


C. Pipe 6T before test. This is an ABS truss composite pipe conforming to ASTM D 2680. Annulus between concentric tubes is filled with lightweight concrete. Exposed surfaces of lightweight concrete were coated with a vinyl resin solution to reduce absorption of water. Photo P801-D-80676



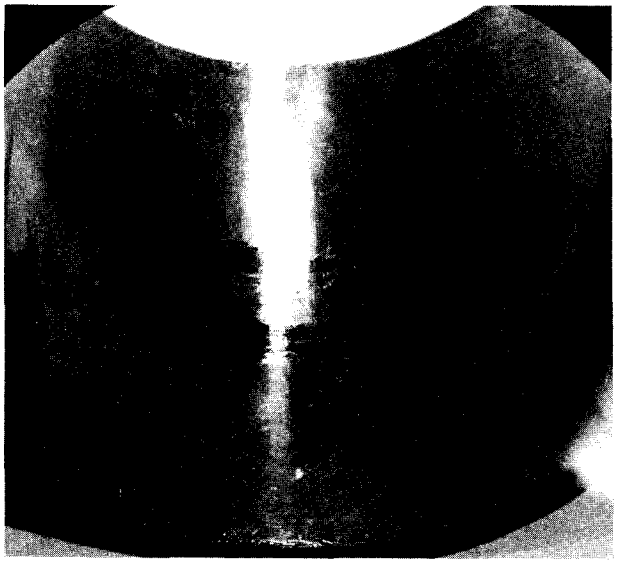
D. Pipe 6T after test. Wear on the liner was minor. Erosion resistance is good. Photo P801-D-80677

Figure 14. — Polyethylene and ABS pipes before and after test.

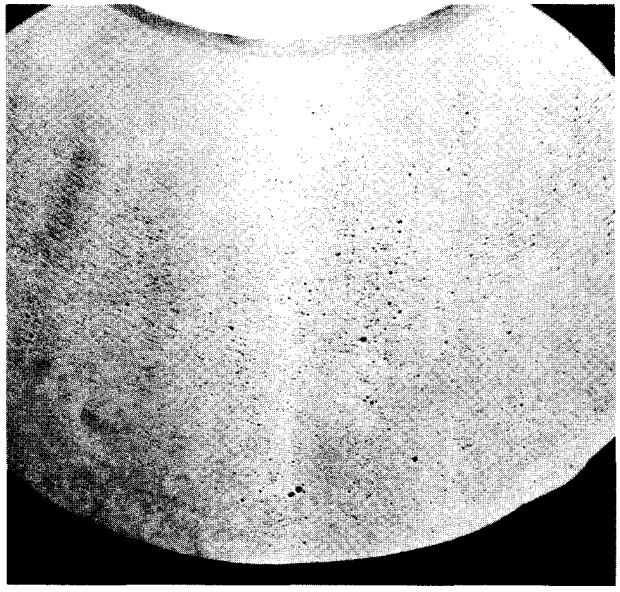


A. Pipe 5S before testing. Liner is composed of aluminum-silicate reinforced polyester resin. This is the same material as that used for the inner surface of some RPM pipes. Photo P801-D-80678

B. Pipe 5S after testing. There is some wearing away of the surface. Liner is rated as having good erosion resistance. Photo P801-D-80679

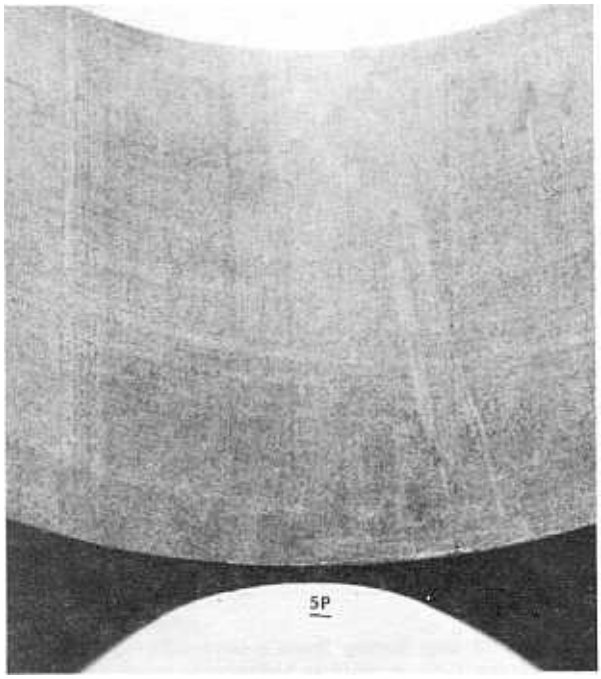


C. Pipe 5T before testing. This pipe is a duplicate of pipe 5S. Photo P801-D-80680

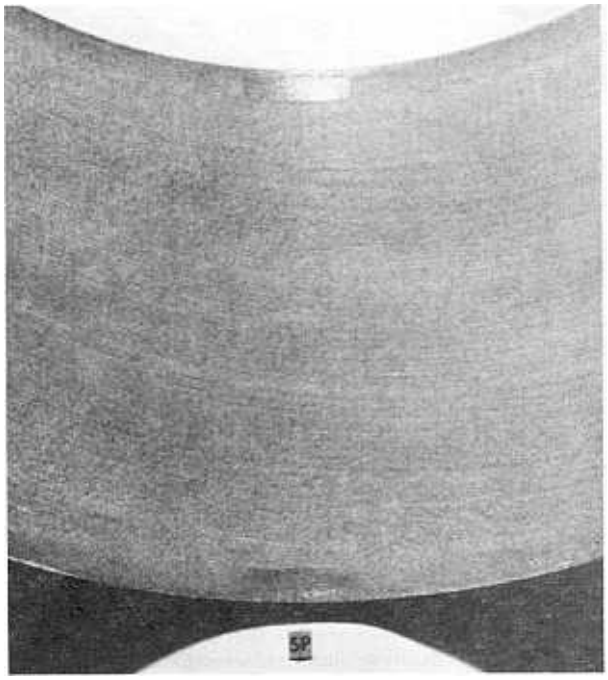


D. Pipe 5T after testing. There is some wearing away of the surface. Liner is rated as having good erosion resistance. Photo P801-D-80681

Figure 15. — Polyester-resin-lined steel pipe before and after test.

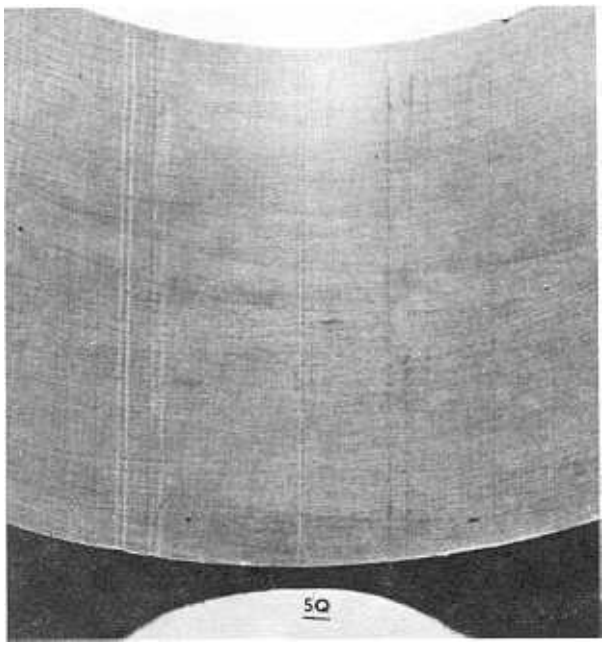


A. Pipe 5P before test. This is an RPM pipe with polyester-resin-rich mortar liner. Photo P801-D-80682

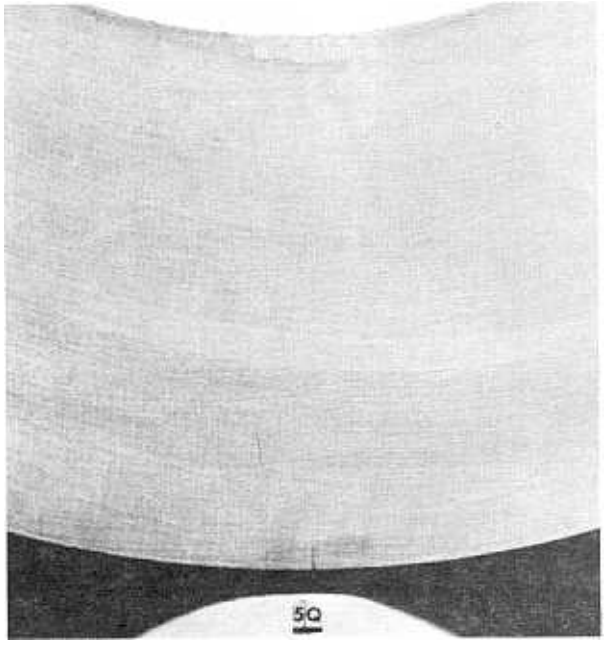


B. Pipe 5P after test. Some wearing away of the liner occurred. Liner is rated as having good erosion resistance. Photo P801-D-80683

Figure 16. — Polyester-resin-mortar-lined RPM pipe before and after test.

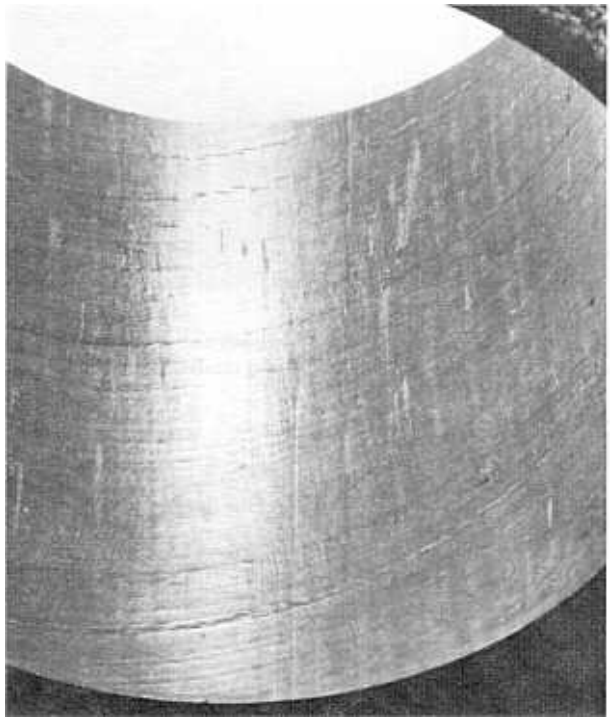


A. Pipe 5Q before test. This is an RPM pipe with polyester-cloth-reinforced, aluminum-silicate-filled, polyester-resin liner. Photo P801-D-80684

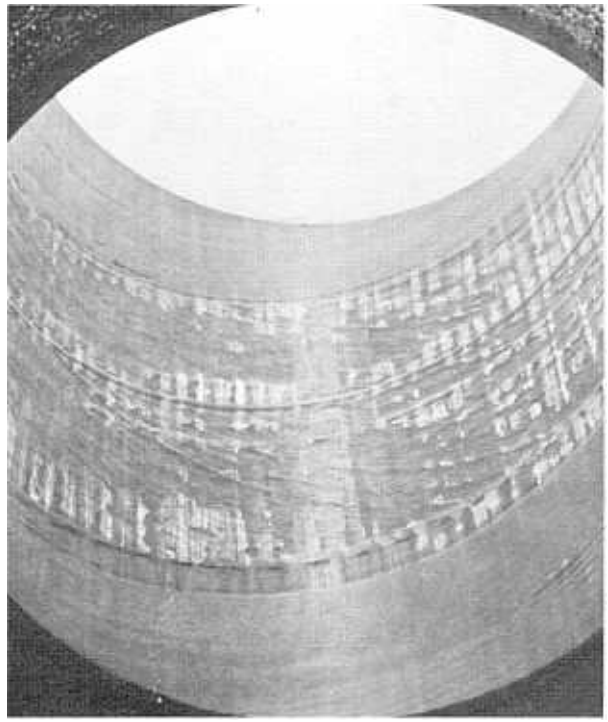


B. Pipe 5Q after test. Some dulling of the surface occurred, and some wearing was evident, but there was no exposure of fibers in the polyester cloth reinforcement. Liner is rated as having good erosion resistance. Photo P801-D-80685

Figure 17. — Polyester-cloth-reinforced polyester-resin-lined RPM pipe before and after test.

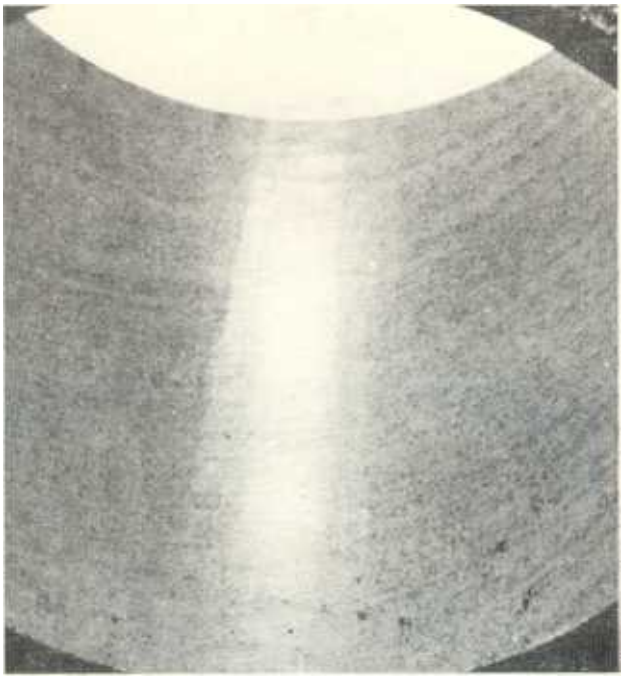


A. Pipe 5X before test. RPM pipe with aluminum-silicate-filled polyester liner. Photo P801-D-80686



B. Pipe 5X after test. There has been significant erosion of the liner during the fourth (No. 4 aggregate) run; about 40 percent of the liner has been worn away. Liner is rated as having low erosion resistance. Photo P801-D-80687

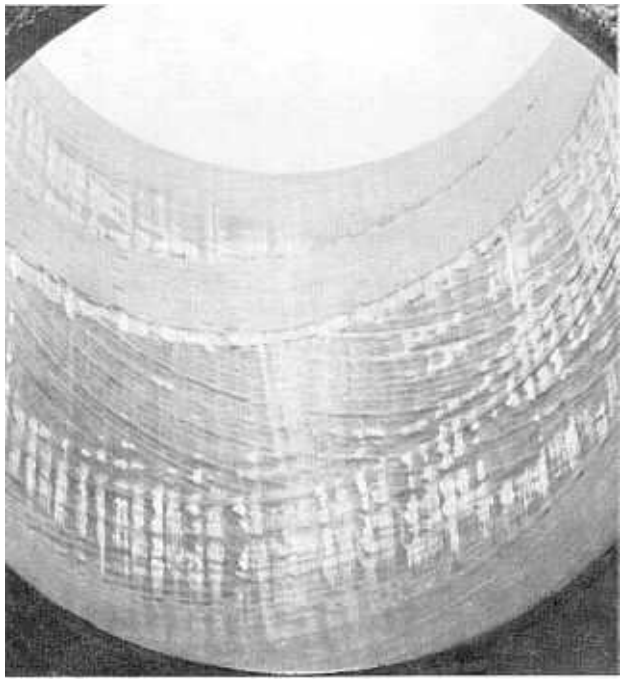
Figure 18. — Filled-polyester-resin-lined RPM pipe (5X) before and after test.



A. Pipe 5Y before test. RPM pipe with polyester-resin-rich mortar liner. Photo P801-D-80688

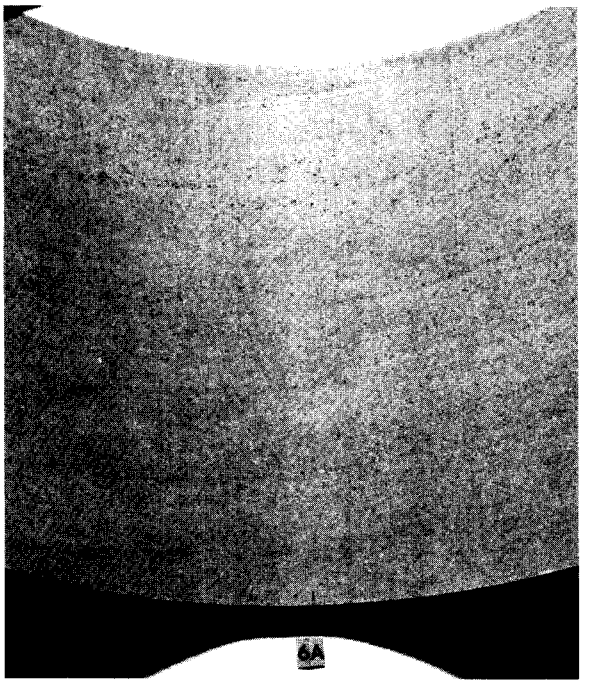
B. Pipe 5Y after test. There has been some wearing away of the liner. Liner is rated as having moderate erosion resistance. Photo P801-D-80689

C. Pipe 5Z before test. RPM pipe with aluminum-silicate-filled polyester resin liner. Photo P801-D-80690

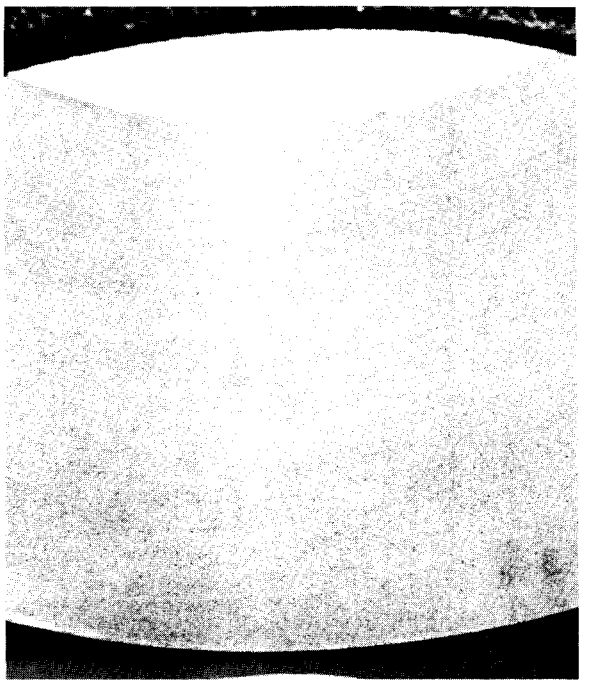


D. Pipe 5Z after test. About 40 percent of liner worn away during fourth run. Liner is rated as having low erosion resistance. Photo P801-D-80691

Figure 19. — RPM pipe before and after test.

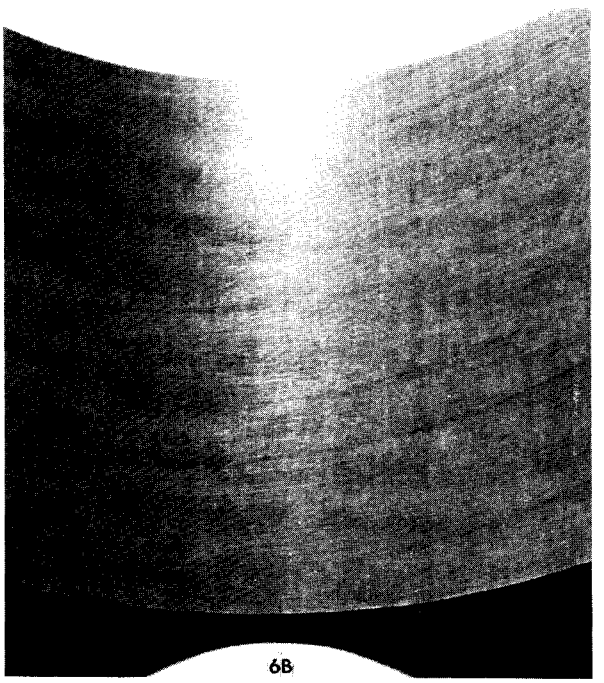


A. Pipe 6A before test. This is an RPM pipe with polyester-resin-rich mortar lining. Photo P801-D-80692

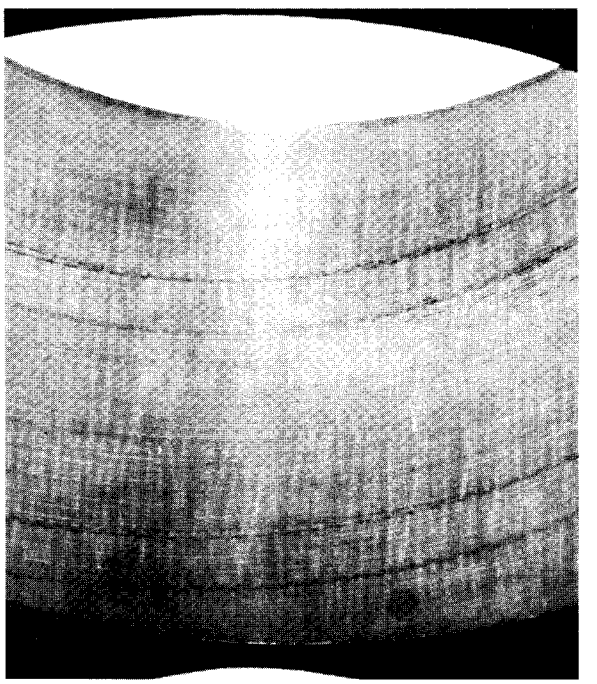


B. Pipe 6A after test. Some wearing away of the liner occurred. Erosion resistance is rated moderate. Photo P801-D-80693

Figure 20. — Polyester-resin-mortar-lined RPM pipe before and after test.

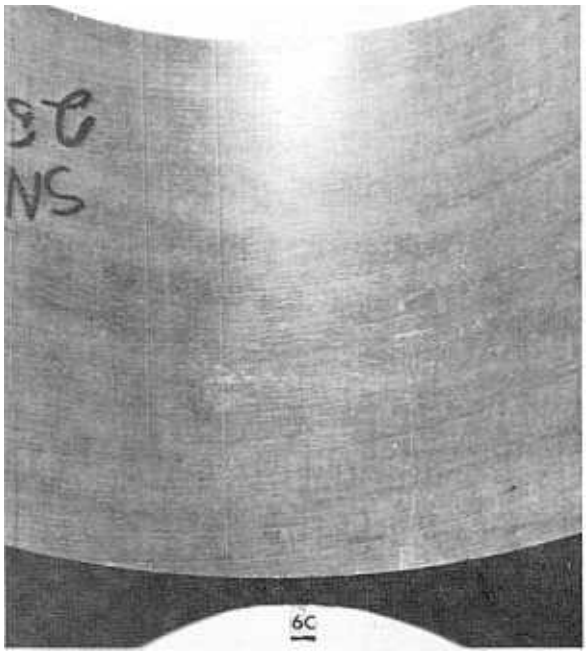


A. Pipe 6B before test. RPM pipe. Liner is composed of aluminum-silicate-filled polyester resin. Photo P801-D-80694

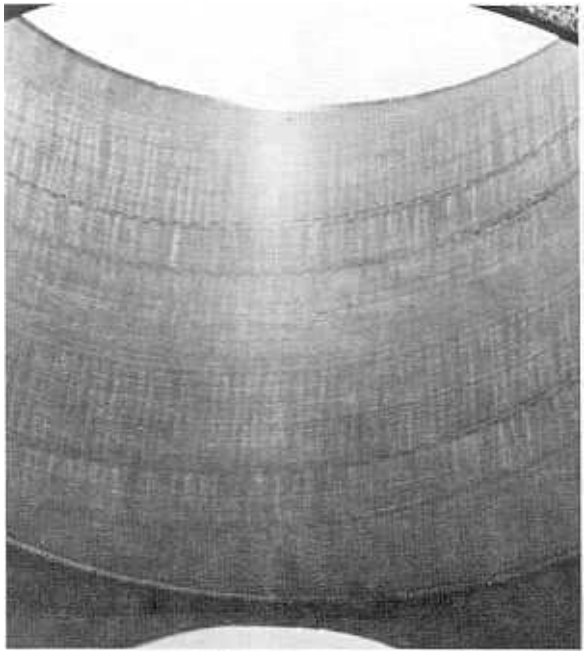


B. Same area as above after test. Erosion losses were slightly less in this area as compared with damaged areas. Erosion resistance is rated good. Photo P801-D-80695

Figure 21. — Filled-polyester-resin-lined RPM pipe before and after test.

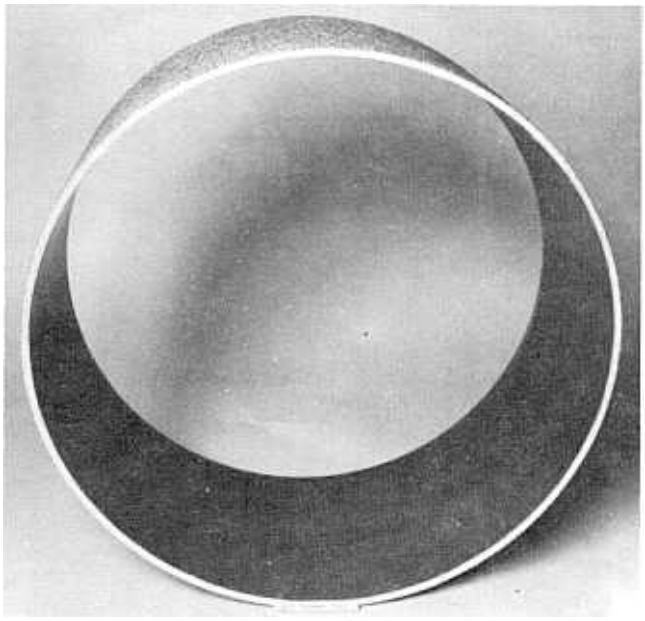


A. Pipe 6C before test. This is an RPM pipe with aluminum-silicate-filled polyester resin liner. Photo P801-D-80696

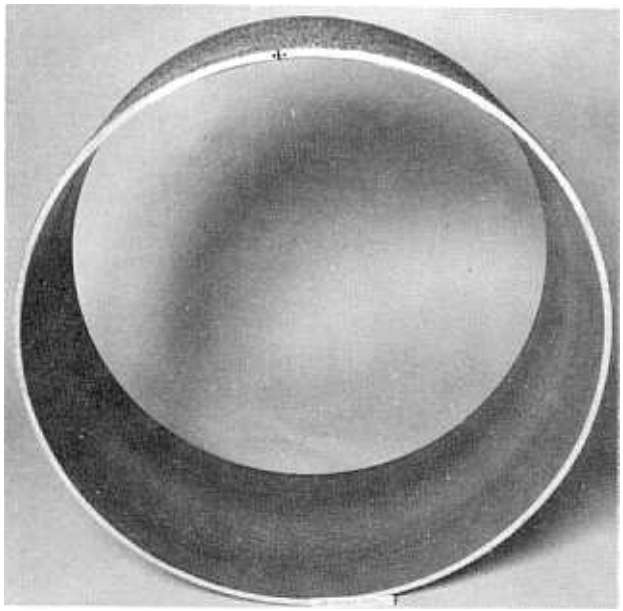


B. Same area as above after test. There is some dulling of the surface and some wear, but the liner is rated as having good erosion resistance. Photo P801-D-80697

Figure 22. — Filled-polyester-resin-lined RPM pipe before and after test.

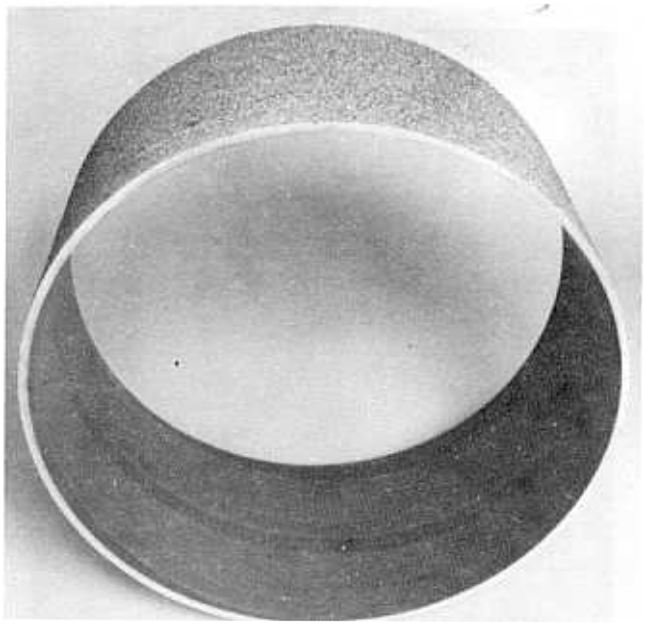


A. Pipe 6Q before test. This is an RPM pipe. The liner is 45 mils thick and is composed of bisphenol polyester resin. Photo P801-D-80698

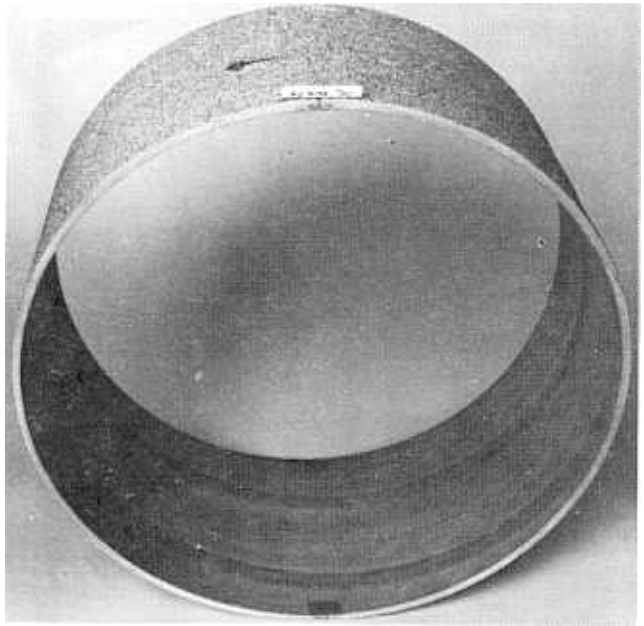


B. Pipe 6Q after test. The main effect is an apparent wearing of the surface; actual thickness loss is very small and the liner is considered to have good erosion resistance. Photo P801-D-80699

Figure 23. — Bisphenol-polyester-resin-lined RPM pipe before and after test.

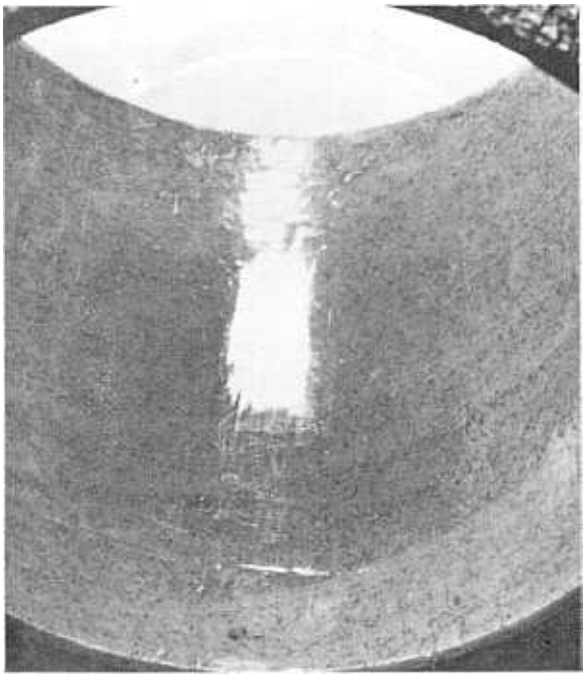


A. Pipe 6U before test. Reinforced plastic mortar pipe with 30 mil isophthalic polyester resin lining. Photo P801-D-80700

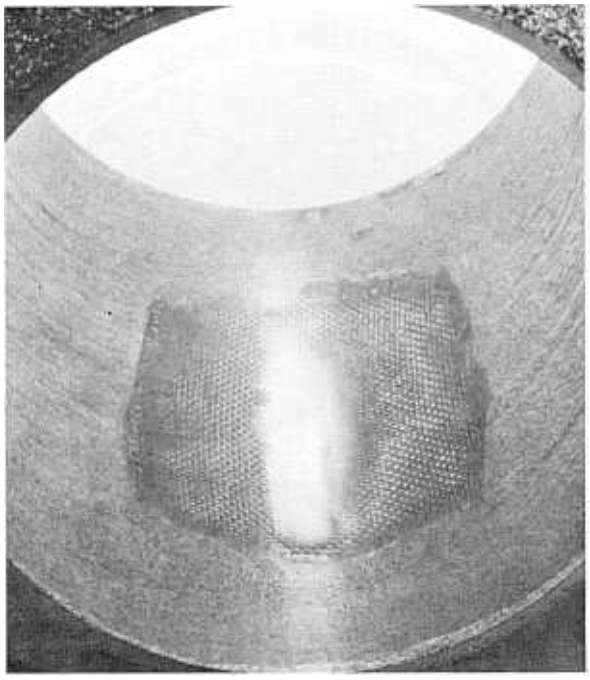


B. Pipe 6U after test. Lining was about 40 percent worn away; erosion resistance is moderate. Photo P801-D-80701

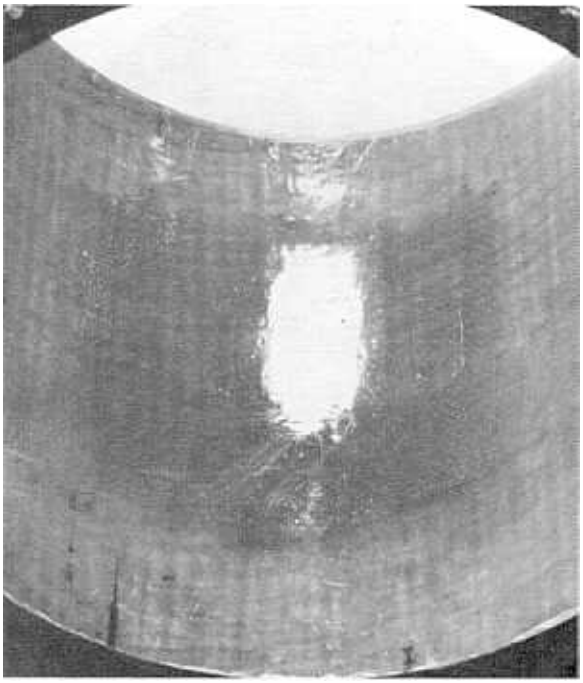
Figure 24. — Isophthalic-polyester-resin-lined RPM pipe before and after test.



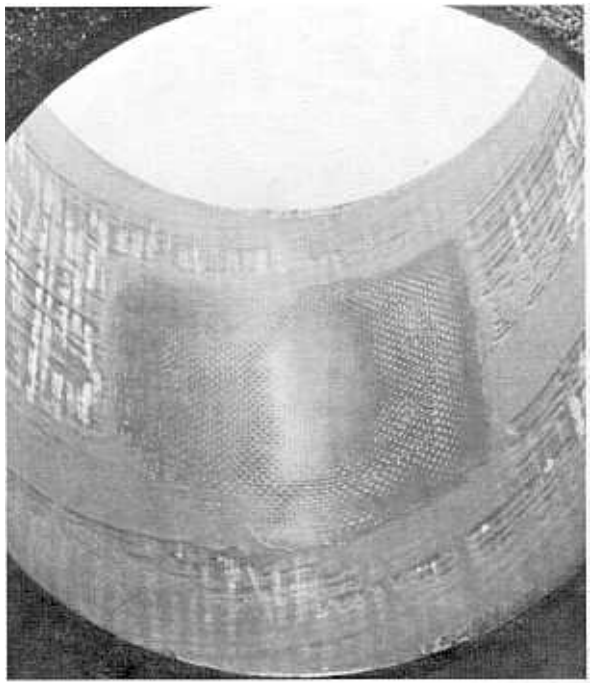
A. Pipe 5Y before test. Same pipe as in figure 19B, except showing area where glass-cloth-reinforced silicate-filled resin repair was made. Photo P801-D-80702



B. Pipe 5Y after test. Wear rate in the repair material is twice as great as in the undamaged area. Photo P801-D-80703

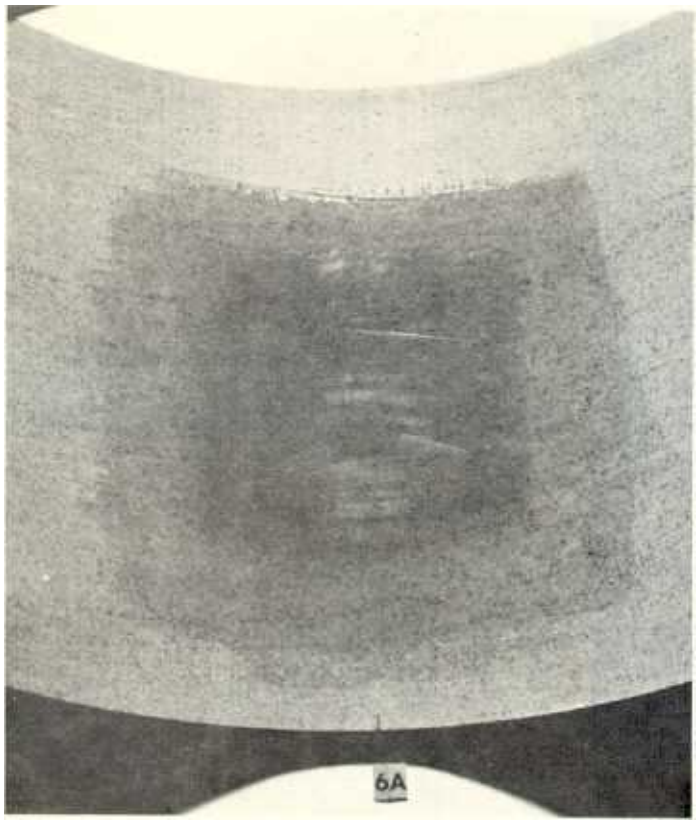


C. Pipe 5Z before test. Same pipe as in figure 19D except showing area where glass-cloth-reinforced silicate-filled resin repair was made. Photo P801-D-80704

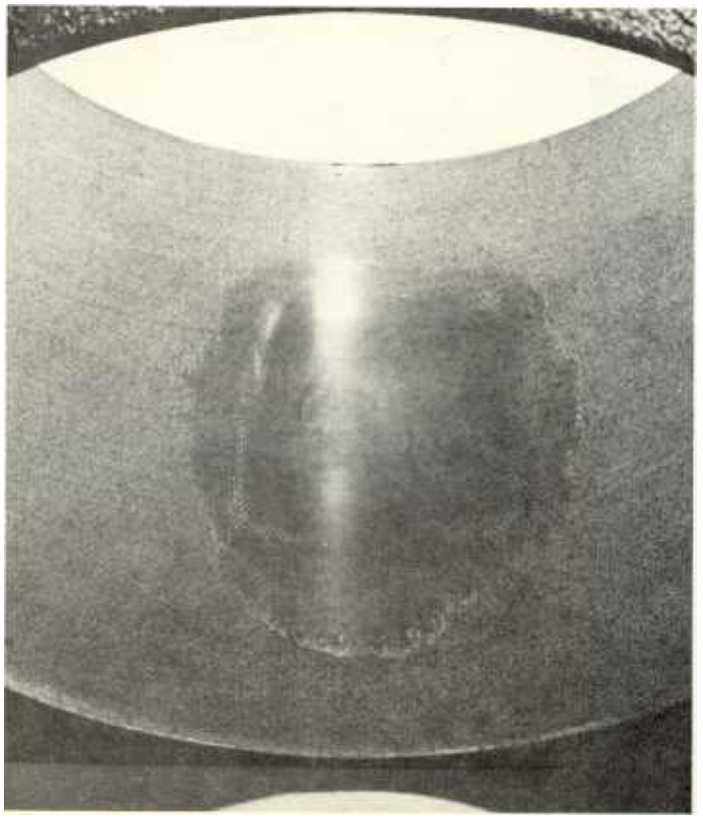


D. Pipe 5Z after test. Wear rate in the repair material was about one-third the rate in the undamaged area. Photo P801-D-80705

Figure 25. — Repaired RPM pipes before and after test.

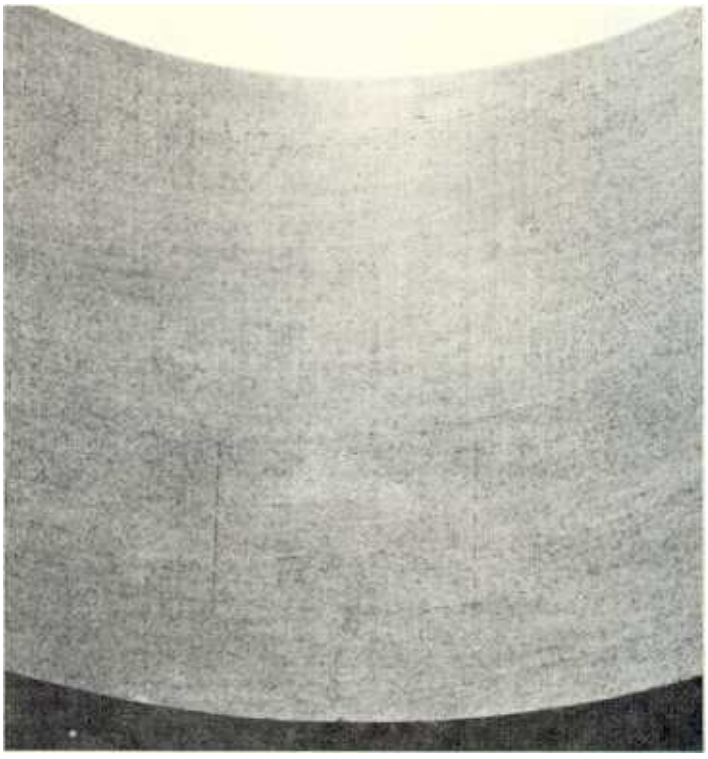


A. Pipe 6A, line I, patched area, before test. Same pipe as in figure 20B. Reinforced plastic mortar pipe with resin-rich mortar lining. Patch is glass-cloth-reinforced aluminum-silicate-filled polyester resin. Photo P801-D-80706

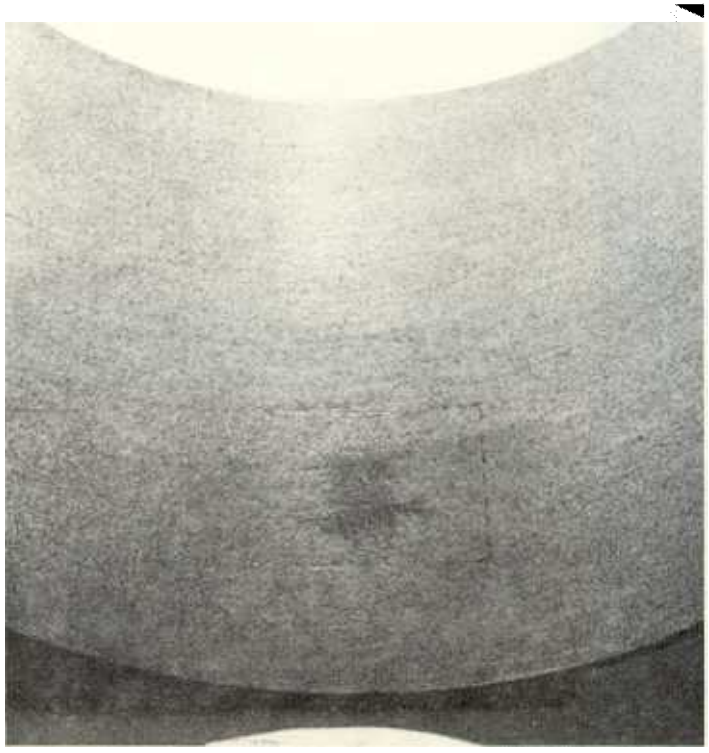


B. Same area as above after test. There is some wearing away of the repair material, most noticeable at the edges of the glass cloth reinforcement. Photo P801-D-80707

Figure 26. — Repaired RPM pipe before and after test.

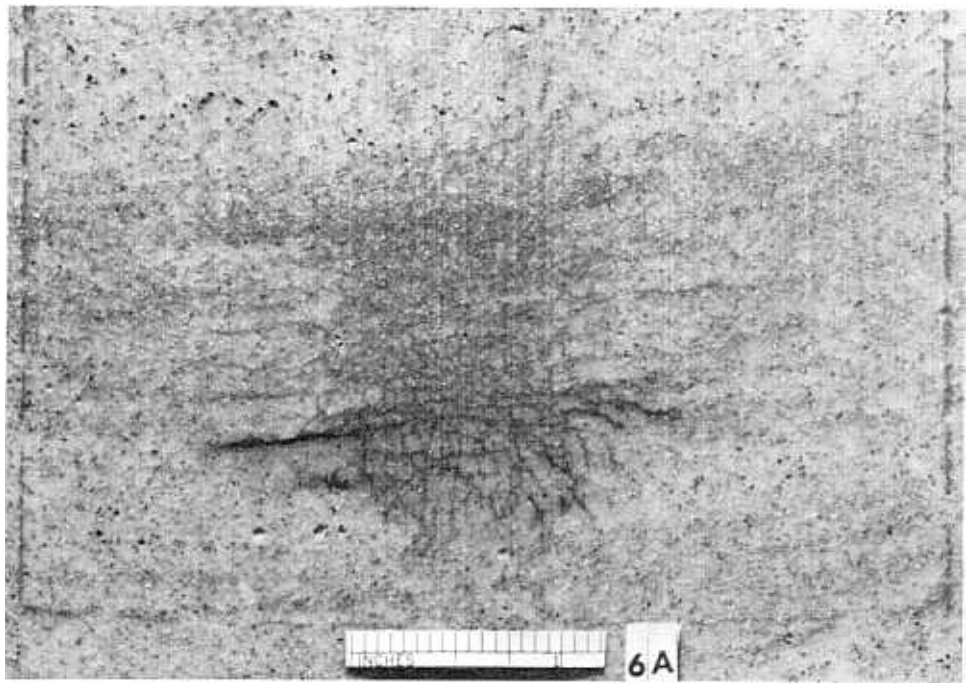


A. Pipe 6A before test. Area outlined was damaged by dropping an 810 gram ball 25½ feet. Pipe was resting on grass during ball drop. Impact was on the exterior surface of the pipe. Same pipe as shown in figure 26. Photo P801-D-80708

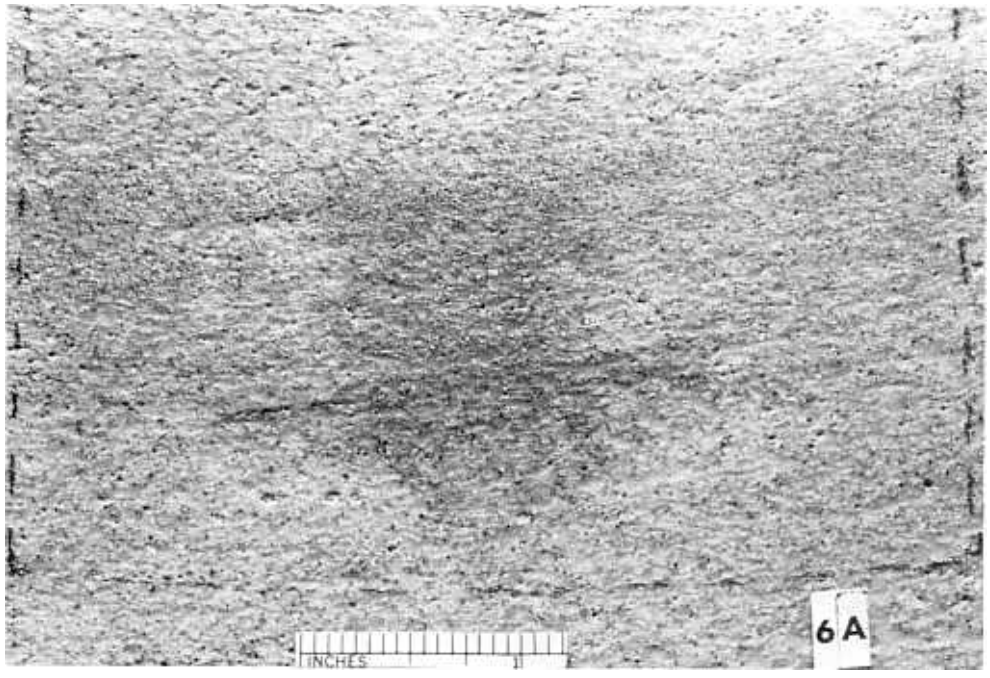


B. Same area as above after test. Dye was used to emphasize and delineate cracks. Wear in the damaged area was no greater than in undamaged areas. Photo P801-D-80709

Figure 27. — Impact-damaged RPM pipe before and after test.

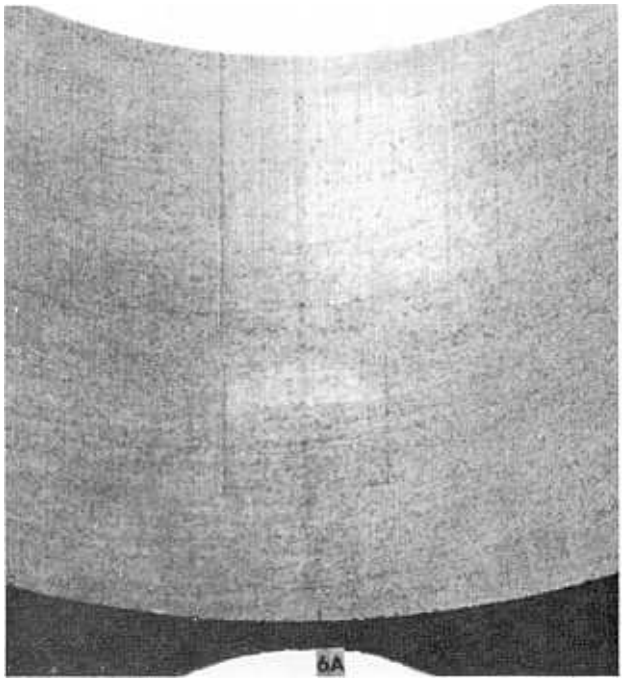


A. Pipe 6A before test. Closeup view of same area shown in figure 27. Dye was used to emphasize and delineate cracks. Photo P801-D-80710

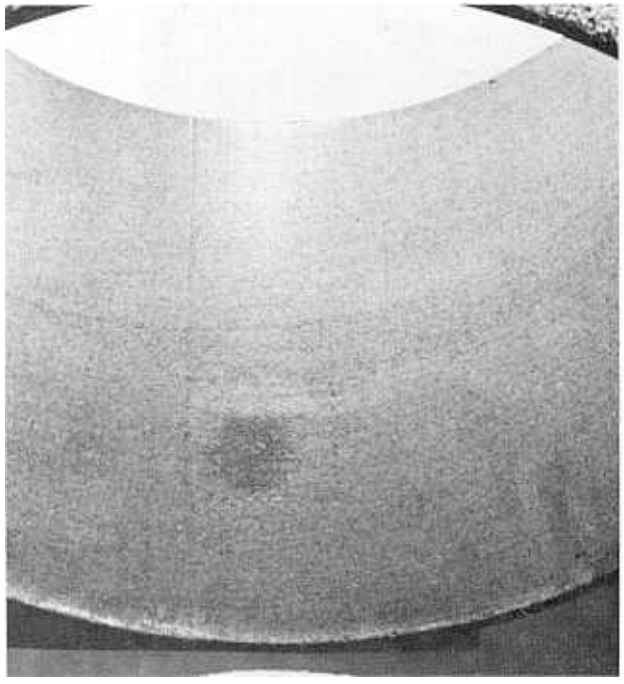


B. Same area as above. Wear in damaged area was no greater than in undamaged area. Photo P801-D-80711

Figure 28. — Closeup views of damaged RPM pipe before and after test.

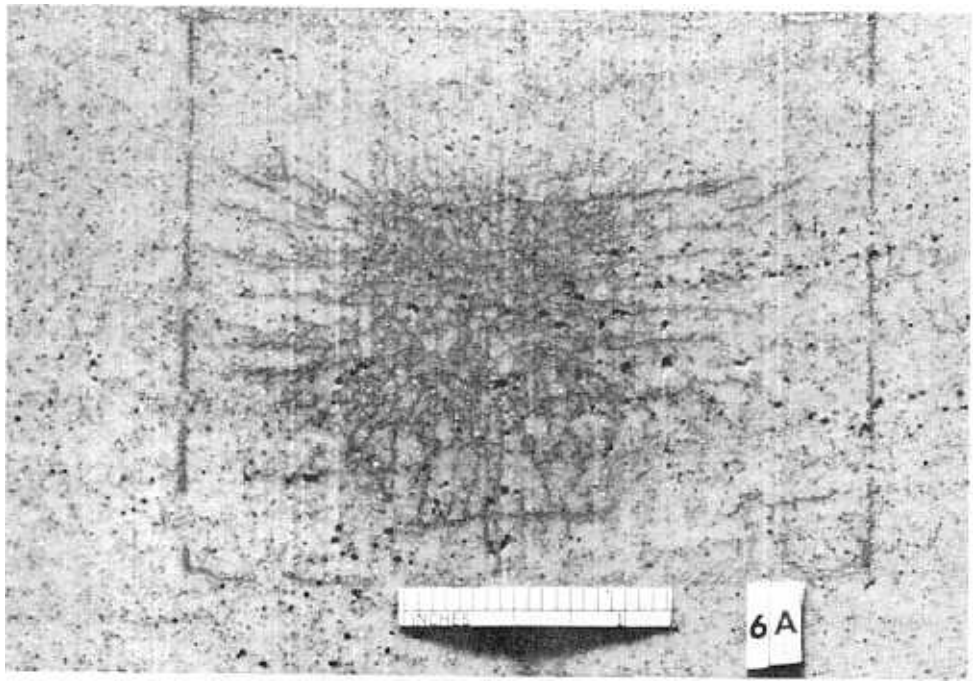


A. Pipe 6A before test. Area outlined was damaged by dropping an 810 gram ball 25½ feet. Pipe was resting on a plywood sheet during the ball drop. Impact was on the exterior surface. Same pipe as in figure 26. Photo P801-D-80712

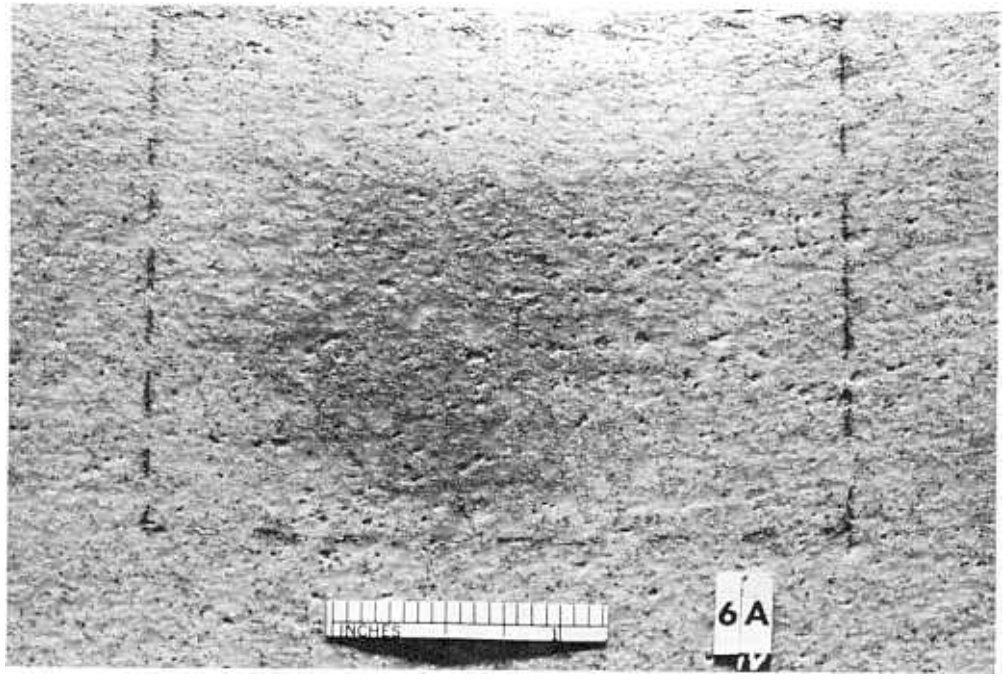


B. Same area as above after test. Wear was no greater in damaged area than in undamaged areas. Photo P801-D-80713

Figure 29. — Impact-damaged RPM pipe before and after test.

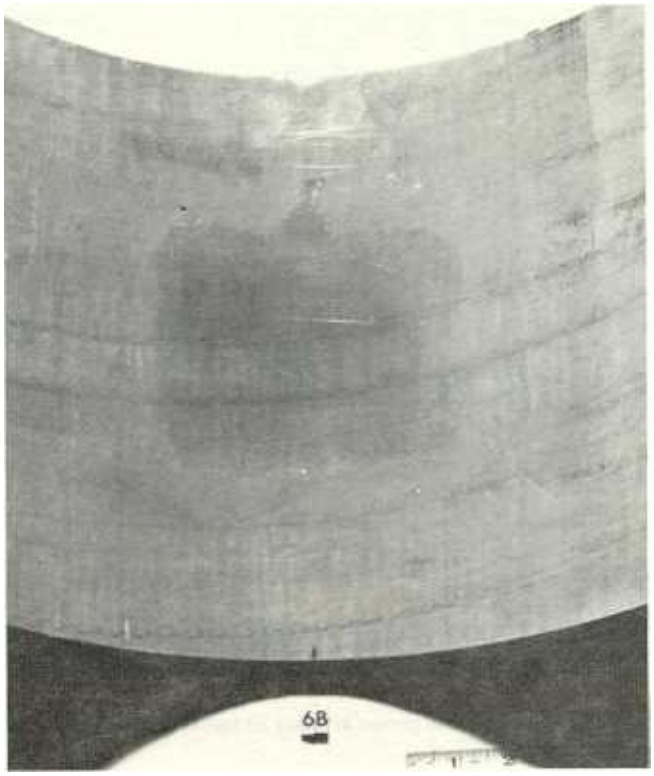


A. Pipe 6A. Closeup view of same area shown in figure 29 before test. Dye used to emphasize and delineate cracks. Photo P801-D-80714

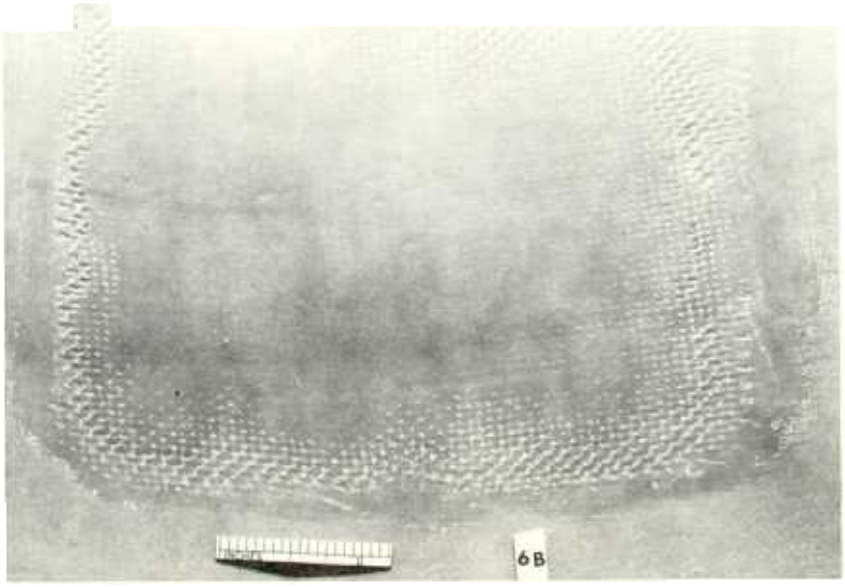


B. Same area as above after test. There is evident wear, but no greater than in undamaged areas. Photo P801-D-80715

Figure 30. — Closeup views of damaged RPM pipe before and after test.

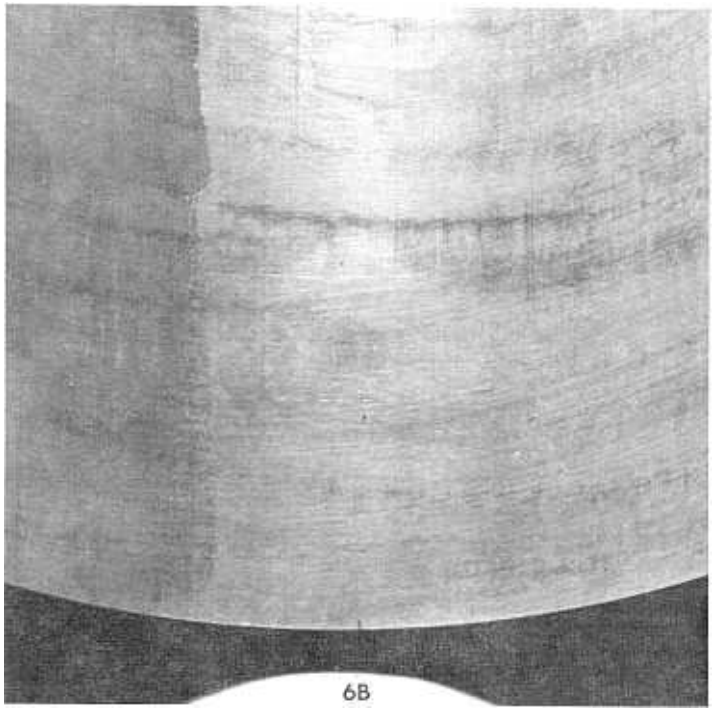


A. Pipe 6B, patched area, before test. This is an RPM pipe. Liner is composed of aluminum-silicate-filled polyester resin. Patch also is aluminum-silicate-filled polyester resin, reinforced with glass cloth. Photo P801-D-80716

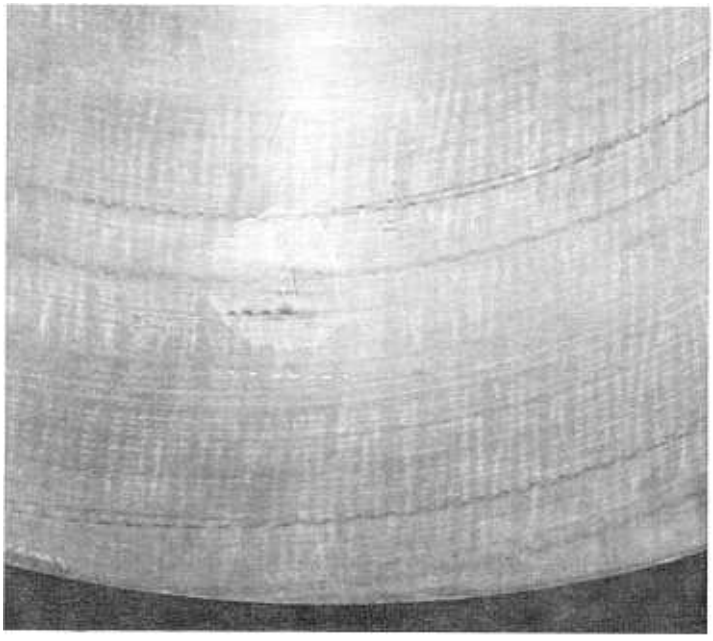


B. Same area as above after test. Closeup view of repair material. There has been significant wear on the repair resin. Photo P801-D-80717

Figure 31. — Repaired RPM pipe before and after test.

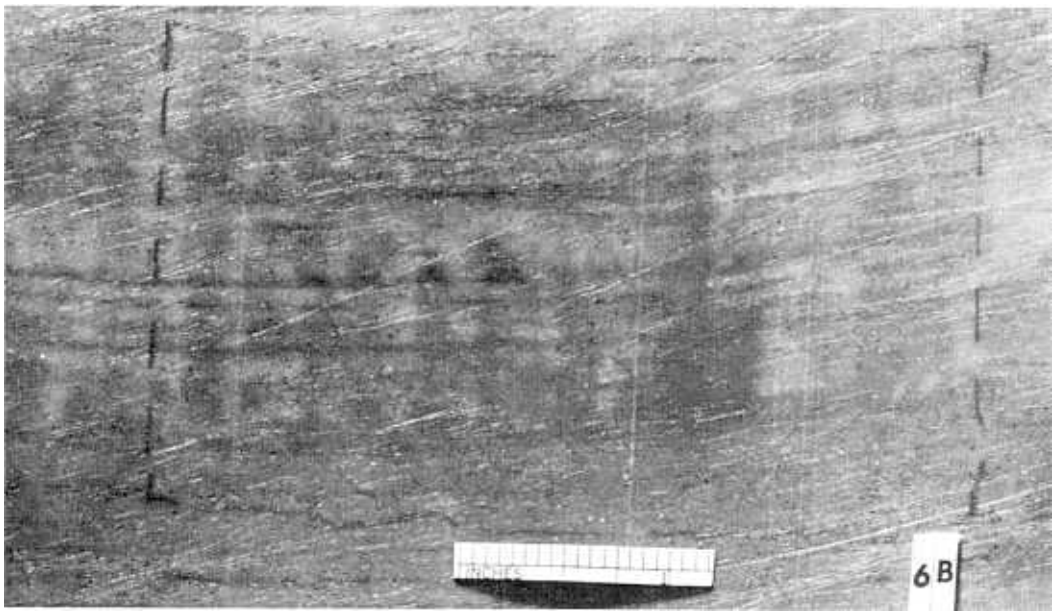


A. Pipe 6B before test. The outlined area was damaged by dropping an 810 gram ball 25½ feet. The pipe was resting on a plywood sheet during the ball drop. Impact was on the exterior surface of the pipe. Same pipe as shown in figure 31. Photo P801-D-80718

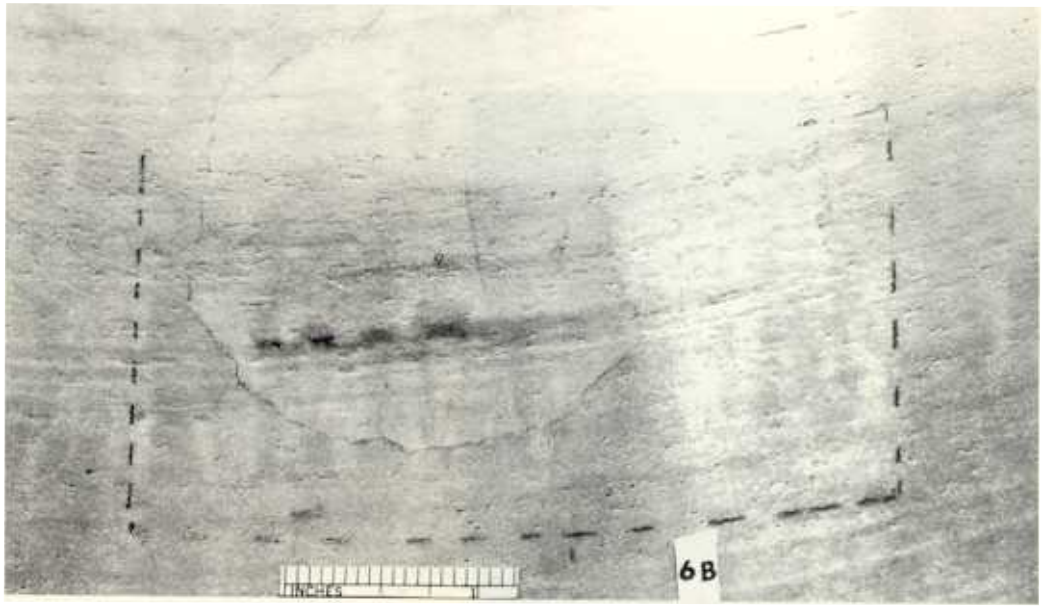


B. Same area as above after test. Erosive wear was no greater on the damaged area than on undamaged areas. Photo P801-D-80719

Figure 32. — Impact-damaged RPM pipe before and after test.

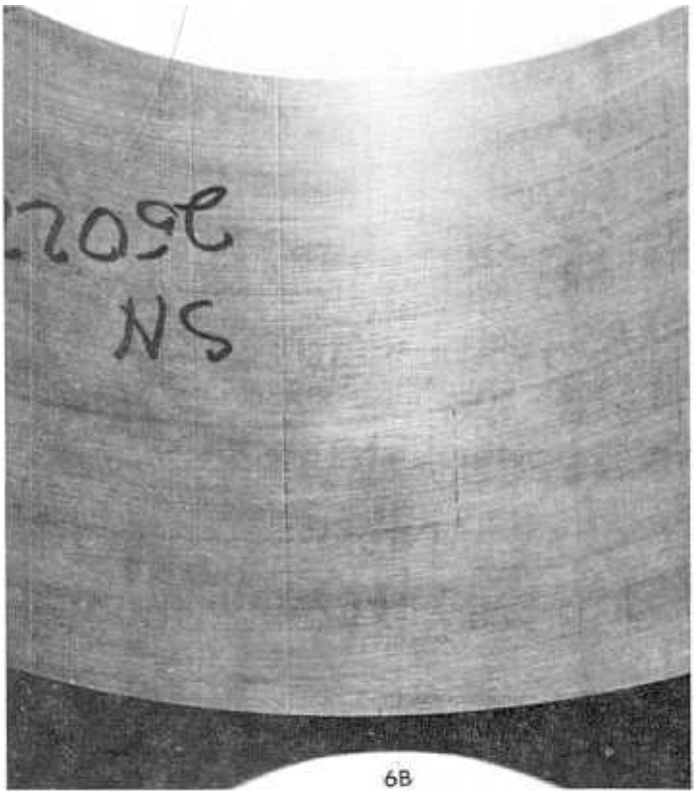


A. Pipe 6B before test. A closeup view of the outlined area shown in figure 32. Dye was used to emphasize damaged spot. Photo P801-D-80720

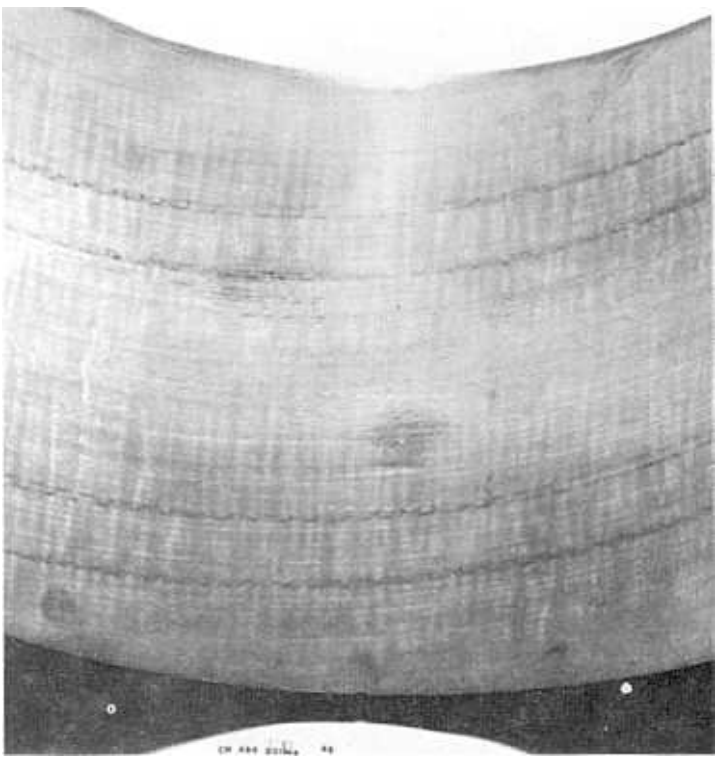


B. Same area as above after test. Wear was no greater than in undamaged areas. Photo P801-D-80721

Figure 33. — Closeup views of damaged RPM pipe before and after test.

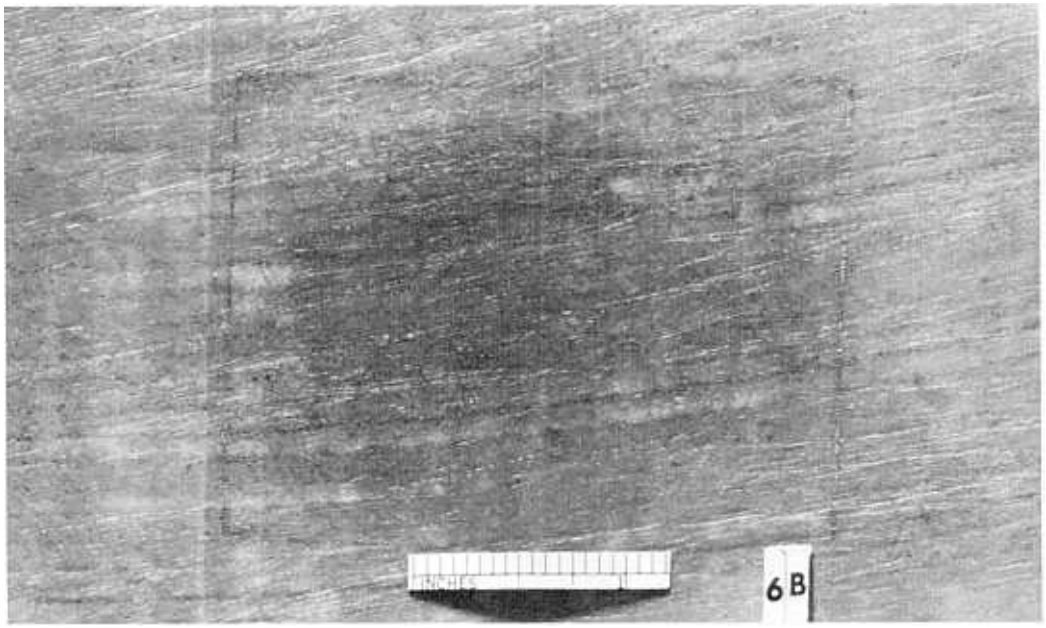


A. Pipe 6B before test. Area outlined was damaged by dropping an 810 gram ball 25½ feet. Pipe was resting on the grass during the ball drop. Impact was on the exterior surface of the pipe. This is the same pipe as in figure 31. Photo P801-D-80722

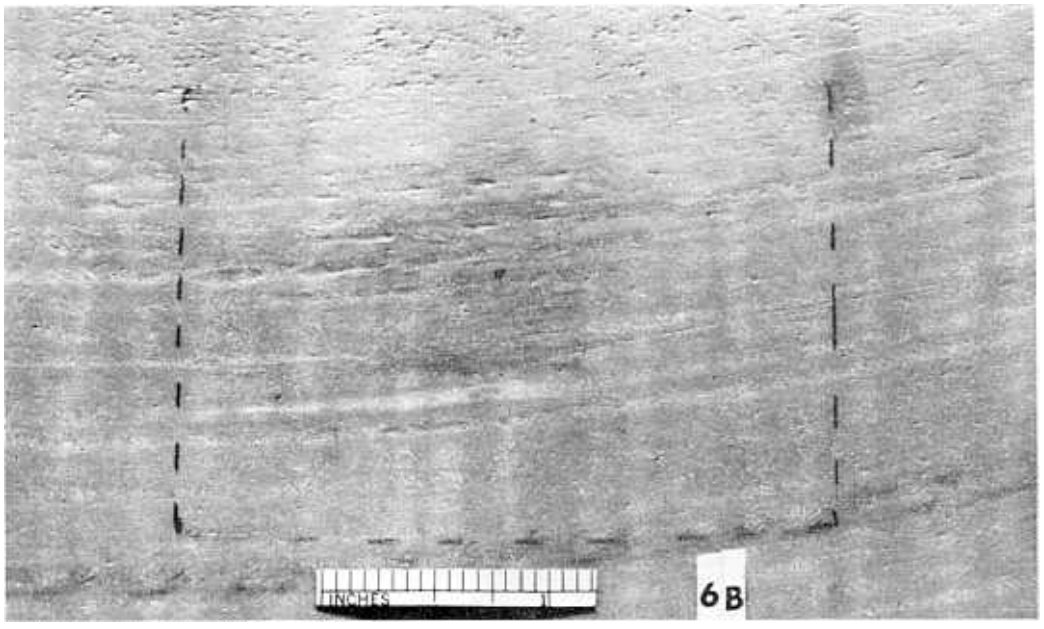


B. Same area as above after test. Wear in the impacted area was slightly greater than in the undamaged areas. Photo P801-D-80723

Figure 34. — Impact-damaged RPM pipe before and after test.

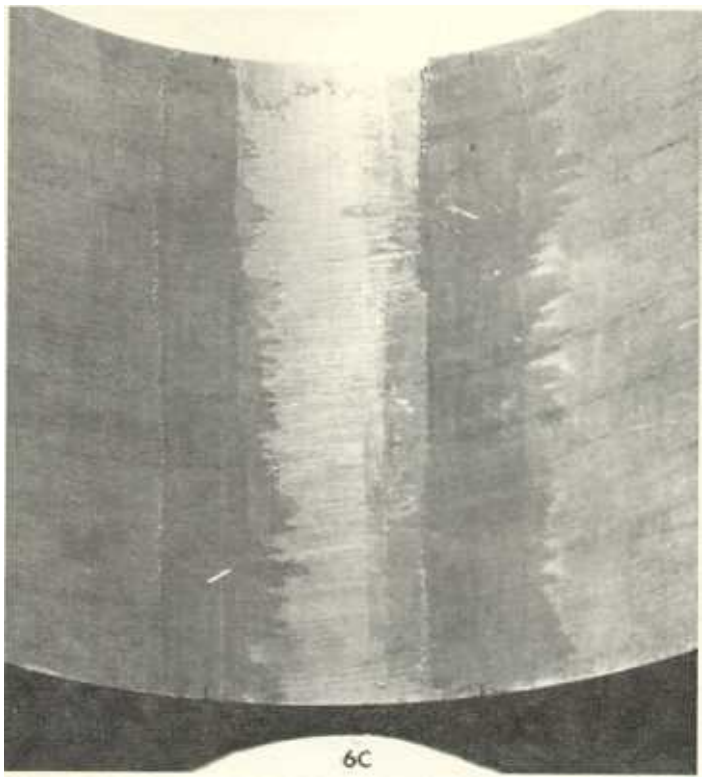


A. Pipe 6B before test. Area outlined was damaged by dropping an 810 gram ball 25½ feet. Pipe was resting on grass during ball drop. Impact was on exterior surface of pipe. Closeup view of same area shown in figure 34. Photo P801-D-80724

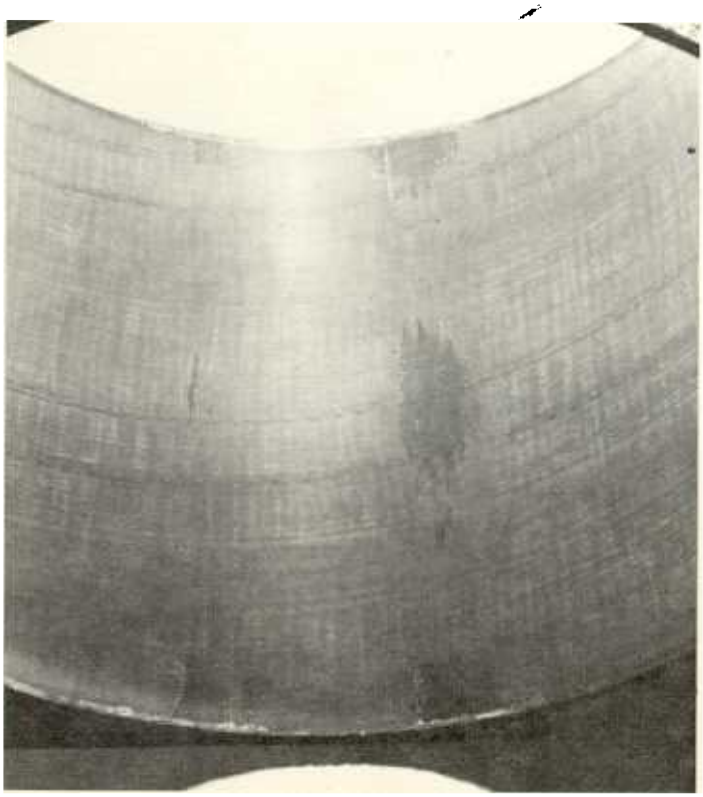


B. Same area as above after test. Wear was slightly greater than in undamaged areas. Photo P801-D-80725

Figure 35. — Closeup views of damaged RPM pipe before and after test.



A. Pipe 6C before test. Same pipe as in figure 22. Longitudinal scratches were overcoated with polyester resin. Photo P801-D-80726



B. Same area as above, after test. Repair resin is almost all worn away. Photo P801-D-80727

Figure 36. — Repaired longitudinal scratches in RPM pipe before and after test.

GPO 845-281

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.