WATER

CORROSION

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Experience With Main Breaks in Four Large Cities

Panel Discussion

A Panel Discussion presented on May 17, 1960, at the Annual Conference, Bal Harbour, Fla.

Philadelphia—Gerald E. Arnold

A paper presented by Gerald E. Arnold, Gen. Supt., Water Dept., Philadelphia, Pa.

PHILADELPHIA has one of the oldest large water systems in the United States. The first part of the system was built in 1799, with wooden mains. Beginning in 1819, cast-iron pipe was laid, and by 1850 all of the wooden mains had been abandoned. The more than 3,000 mi of pipe within the city limits varies in age from a few months to more than 130 years. Main breaks occur frequently in a system of this size and age. As many as 1,000 breaks have been recorded in a single year, with a maximum of 300 a month during the colder months. Breaks have occurred in all sizes of pipe, from 3 in. to 48 in., at various locations in the city, at different pressure levels, and under varying conditions of traffic and other external forces.

Temperature Changes

The majority of water main breaks in Philadelphia occur during the three coldest months of the year, January, February, and December. During this period the water temperature reaches its lowest point of the year. The temperature at the intakes from the rivers is generally close to 32°F, and the temperature throughout the system seldom rises above 35°F during the winter months. Frost penetration in Philadelphia varies from 12 in. to 30 in., depending on the duration and severity of the cold weather. It has been noted that the greatest number of breaks usually occurs at the time of the winter when the temperature is dropping most rapidly for the first time. It is believed that the sudden chilling of the water and the surrounding earth results in shrinkage of the pipe metal, thus setting up sufficient longitudinal stresses actually to pull the metal in two at points where it has already weakened. The majority of the breaks found under these conditions are circumferential cracks, with little longitudinal deviation. Most of these breaks can be repaired by installing a split clamp around the crack. Some cracks of this type occur at other times of the year, but those are believed to be due to beam action from blocking under the pipe or to other external forces.

An unusual occurrence during April 1960 is worthy of note. The month

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of March 1960 was one of the coldest of record, and April was one of the warmest of record, temperatures exceeding 90°F on several occasions, which is unusual for Philadelphia in April. During April 1960, there were 50 water main breaks, compared to 23 for April 1959. The 1960 record temperature was 30 per cent above the average for that month. It is believed that these breaks were occasioned by rapid and unusual temperature rises.

Pressure Changes

Changing pressures in water systems can cause main breaks, particularly if those pressure changes are sudden, such as those associated with water hammer or rapid changes in operating pressures. A number of years ago, a pressure change was made in part of the Philadelphia distribution system which raised the pressure only about 10 psi but resulted in eighteen main breaks in a single hour. The points at which the mains broke with this slight pressure change were already weakened by some other cause. The author had an experience a number of years ago with another water system in which day and night pressures varied as much as 100 psi owing to unfavorable operating conditions. This resulted in some serious breaks in a 16-in. supply line.

Supporting Ground

Another common cause for water main breaks is shifting or settling ground. Pipe that is normally supported throughout its length should be subjected to few bending strains. If the ground shifts or settles unevenly the transmittal of beam forces to the pipeline can set up strains that exceed the tensile strength of the metal.

Serious difficulty has frequently been encountered with a 48-in. line on Broad St. in Philadelphia, where the line is carried on concrete piers over the top of a subway. Uneven settlement of these piers has resulted in a distortion of the pipe, transmitting unusual stress to the metal. Frequent breaks have occurred in this line, and, in some instances, it has been found that the pipe was not resting on the piers, which would normally support it from below, either at the point of break or at an adjacent pier. Surveys of this pipeline have indicated wide deviations from a straight alignment. Most of the breaks have been at the bell with a circular crack running one-half or two-thirds of the length of the joint and returning again to the bell, with the result that a large segment of the pipe is broken away completely. This pipeline is also subject to vibration of traffic from above and subway trains from below. In addition to breaks in the pipe itself, there have been frequent joint leaks, indicating that the pipe is moving.

Electrolysis

Another detrimental action that weakens pipe metal is soil corrosion, or stray-current electrolysis. Corrosive soils or stray currents tend to eat away the metal from the outside of the pipe, usually in concentrated locations, thus producing a thin wall or complete breakthrough in small areas. Removal of metal from the pipe wall, of course, also weakens the wall so that any unusual strain may result in a break. The problem of stray-current electrolysis is becoming increasingly serious in cities where there has been a partial abandonment of the streetcar system. Often the abandoned tracks, when they are no longer used for streetcars, are paved over and used as a return path for the current supplying operating tracks. These old rails being paved over, are not properly maintained, and open joints frequently develop resulting in discharge of large quantities of current to the ground and underground structures, such as pipelines. When one recalls that 1 amp of current will remove 20 lb of metal in a single year, there is a definite reason for concern when as much as 600 amp is found traveling on an underground piping system.

Traffic

Traffic conditions have materially changed in recent years. When many of the pipelines were laid 50–100 years ago, street traffic consisted of horse-drawn vehicles. Today, modern motor trucks, weighing as much as 30 tons, pound the depressions in streets and transmit shock waves to all underground structures. The standard practice in Philadelphia has been to bury water pipe with at least 4 ft of cover. In the old days, this was sufficient, but with modern traffic loads it is felt that more cover should be provided or that there should be a very heavy concrete base under the pavement to take the impact of traffic shock. It has been noted some main breaks have followed the development of chuck holes in the street where heavy trucks pounded into these holes, setting up noticeable vibrations.

Age of Pipe

Extreme age does not necessarily indicate poor condition of pipe. Many miles of pipeline in the Philadelphia system are more than 100 years old and are still rendering satisfactory service with comparatively few breaks, whereas other pipe 50–75 years of age has had more frequent breaks.

A study of the pipe removed from the system indicates that there is very little weakening of the metal due to internal corrosion. Tuberculation of the interior surface is evident, but pitting of the metal is negligible. External forces or corrosion factors are much more important than internal corrosion. A study of pipe removed after many years of service indicates that wall thicknesses are materially reduced from the outside. In most instances metal has been removed in spots, leaving noticeable cavities and a few fairly extensive areas of thin metal.

Construction and Operation

Good construction is the best way to avoid water main breaks. A study of breaks in Philadelphia has led the author to believe that much of the trouble was occasioned by improper construction methods. Blocking was utilized in Philadelphia for many years, and it is the author's firm conviction that this was responsible for many breaks. Blocking should be prohibited. The standard practice in Philadelphia now is to encase the new main in 6 in. of clean sand. The trench is excavated to 6 in. below the bottom of the pipe and backfilled with sand; the pipe is firmly bedded in the sand, and, after the joints have been made, sand is placed around the pipe to a full thickness of 6 in. The balance of the trench is then filled with exacavated material, excluding broken concrete, stone, or other debris. The backfill is thoroughly tamped in thin layers to the surface of the ground and then allowed to settle and become thoroughly compacted before paving is placed. To lessen the shock of traffic impact, a base course at least 6 in. thick should be made of poured concrete and topped off with asphalt or some other finish coat. Excavations for repairs and maintenance work should be backfilled in the same manner.

All pipe should be thoroughly inspected at the plant and again on the job site before installation. Old records of the Philadelphia Water Department indicate that pipe inspected on the job 50–60 years ago was subject to about 20 per cent rejects. Manufacturing is probably much better today than it was at that time, but piping is still subject to damage after it leaves the factory and before it is installed. Tests at pressures at least 50 per cent higher than normal working pressure should be made before the line is accepted from the contractor.

Cities having surface streetcars should make a study of the electrolysis problem, particularly if some of the streetcar lines have been abondoned and the rails are still in place and used for negative return current. Continuing electrolysis studies should be made to see that the water system is not being damaged by stray currents. Soil surveys should be made in advance of construction to determine whether or not special protection is necessary to prolong the life of the new pipeline. The installation of rectifiers, insulating, or bonded joints may be highly desirable, and their cost is but a fraction of the cost of replacing a pipeline.

Care should be exercised to avoid frequent wide fluctuations in pressure. A pipeline carrying water at pressures varying as much as 50–100 psi actually deflects with the pressure changes, and metal fatigue may result in serious breaks. Whenever a break occurs, a study of the attendant conditions should be made before the trench is backfilled. This will enable the operators to ascertain to some degree the cause of the break and assist in designing to avoid repetition of the failure in the future. In some instances breaks take place for no apparent reason. On several occasions the author has seen cast-iron lines in which a section of the pipe broke out on one side or the bottom in the middle of a joint without cracking the bell or the spigot. The metal surrounding the break appeared to be sound and there were no unusual operating conditions that could account for the break.

Flexibility at the joints is another factor which, it is believed, can reduce the number of breaks. With the new type of rubber ring gasket, there is much more flexibility than there was in older types of joints. Movement at the joint relieves stress in the metal and should be helpful in reducing the number of breaks.

Conclusion

Water main breaks usually occur at a point where the metal has been weakened by corrosion or some other cause, but the actual breaking of the metal occurs as a result of some unusual external force such as temperature changes, shifting ground, foreign objects, or traffic impact. Weakening of the metal is a result of age, but age is not necessarily the most important factor. Once the metal is weakened, an unusual strain may result in a fracture of the metal. In the author's opinion, sudden temperature changes are responsible for most breaks, although other factors may be involved. Water main breaks should be studied as they occur by a qualified engineer, to determine, if possible, what caused them. By studying this information and following good construction practices, many of the water main breaks experienced in the past can be avoided in the future.

New York—Edward J. Clark

A paper presented by Edward J. Clark, Chief Engr., Bureau of Water Supply, Dept. of Water Supply, Gas & Electricity, New York, N.Y.

Water main breaks have always presented considerable problems to water supply engineers, not only because they disrupt the supply and are expensive, but also because of damage caused by the flooding of subways and basements, the upheaving of pavements, interference with vehicular traffic and transit service, and other inconveniences suffered by the public.

Causes of Breaks

Breaks in cast-iron mains may be caused by flaws in pipe and castings; internal pressure in excess of that for which the pipe was designed; deterioration of metal due to corrosion; electrolysis; freezing of exposed pipe; excessive earth load due to depth of cover over pipe; unbalanced pressures in the line such as at bends and caps; unequal settlement of the soil in which the main is laid; settlement of other subsurface structures crossing the water pipe, such as electric conduits or gas and steam mains; vibrations due to blasting in close proximity to the main; and other causes.

In the New York system, the number of breaks due to defective pipe and castings, excessive internal pressure, deterioration of metal, electrolysis, or freezing is negligible. Many water main breaks have been caused by settling of the main over short stretches. This causes the pipe to act as a beam, for which it is not designed, and results in fractures or loose joints. Settling of a water main over short stretches may be caused by improper bedding or by the gradual wearing away of soil under the main as a result of a small leak from a pipe joint.

A substantial number of breaks in New York has been caused by unequal settlement of water mains along subway routes and the settlement of subsurface structures, such as electrical conduits or gas and steam mains, crossing the water pipe and resting on it.

It is sometimes difficult, if not impossible, to determine the exact cause of a specific break, as the subsurface conditions existing when the broken main is exposed may be entirely different from those prior to the break. There is no way of knowing what the prior conditions were.

The New York distribution system comprises about 5,800 mi of mains incorporating some 4,000,000 pipe joints, 450,000 pipe fittings, 165,000 gate valves, and 90,000 hydrants. For the past 10 years, there has been an average of 330 breaks each year (almost one a day), 20 of which have been in 20-in. pipe and larger, with the majority in the 6–8-in. sizes. Although there is no specific pattern as to time of day breaks occur, it appears that many of them take place during the early morning hours. This may be due to the sudden opening of existing splits in the pipe as a result of slight increases in internal pressures during the early morning hours when the water demands are low.

Preventive Measures

The steps that have been taken to minimize breaks include improved construction methods and strict inspection of materials and installations. The use of steel pipe for all mains larger than 20 in. has been standard practice in New York for the past 30 years.

Specifications for water main installations require:

1. Well tamped bedding of clean earth or sand under, around, and over the pipe
2. Consolidated backfill to distribute the traffic loads
3. Installation below the frost line to prevent heaving
4. Use of rods on bends and fittings to help the pipe withstand unbalanced pressures
5. Proper assembly and calking of lead joints to prevent leaks
6. Hydrostatic field testing of pipe (All mains 20 in. or larger are subjected to hydrostatic field tests at 125 psi, and in certain other cases, such as bridge crossings, similar tests are required on mains smaller than 20 in.)
7. Reinforced-concrete mat, with cradles or pile supports, in areas of fresh fill, swamps, and other places where the bearing capacity of the soil is poor
8. Concrete cradles under the pipe in rock trenches.

In an effort to reduce the number of leaks and breaks, an inspection force is maintained at the foundries where the pipe and castings are made, to make sure that the materials are sound and are being manufactured in accordance with specifications. Also, all water main installations have competent inspectional supervision to insure the strict enforcement of all contract specifications. The water department also has a special force engaged in systematic surveys to detect and eliminate underground leaks. Such leaks, which do not appear at the surface, may cause the gradual erosion of soil under the main and thereby result in unequal settling of the pipe and possible rupture. Approximately 600 leaks from joints, split pipe, taps, services, and gate valves are detected yearly, thus effecting an average saving of 25 mgd.

As mentioned before, the use of steel pipe for mains larger than 20 in. is another safeguard adopted to curtail breaks in large mains and thereby reduce flood damages, disruption of traffic, and other inconveniences. To minimize the effects of electrolysis on steel pipe, insulating joints are installed in the line, and, in some cases, cathodic protection is provided.

Remedial Action

New York has had many breaks in large mains which have resulted in a great deal of flooding and disruption of subway traffic.

When breaks do occur, the first action taken is to shut down the feeds to the main in the shortest possible time in order to minimize damages. For this purpose, emergency crews are maintained on a 24-hr basis and have trucks equipped with motorized valve-operating devices as well as short-wave radios to speed up operations.

Narrows Siphon Incident

Perhaps the most serious break, and certainly the most difficult one to repair, was the break in a 36-in. cast-iron submarine pipeline crossing the narrows in New York Bay and supplying the Borough of Richmond with water. The nature of the pipe fracture indicated that it was caused by one of the spuds of a large dredge, which had been working directly over the pipeline at the time of the break.

When the break occurred, a gage located in one of the pumping stations recorded a sudden drop in pressure from 70 to 28 psi. Within 15 min, it was determined that the drop in pressure had to have been caused by a break in the narrows siphon, as a venturi meter showed that a large quantity of water was flowing in the pipe at the Brooklyn end, but no water was reaching Richmond. Backflow from Richmond was prevented by a check valve in the pipeline near the waterfront. Within an hour after the break occurred, the Brooklyn end of the line was shut down, stopping the 28-mgd flow that had been wasting into the bay.

Siphon Repairs

Because the narrows siphon furnished more than two-thirds of the supply for Richmond and local sources could not possibly have met the demand once the storage in the distribution reservoir had been consumed, immediate action to effect repairs had to be taken. Under the emergency powers of the commissioner of the department, a dredging company was engaged to examine the line and make repairs. Three hours after the break, the company had some of its plant on the job and started pumping air into the pipeline to locate the leak. After 2 hr, the air began to show at the surface of the water, indicating the break to be about 170 ft from the end of a pier on the Richmond side. At that point the pipe was under 30 ft of water and 20 ft of harbor muck and fill. The contractor started immediately to excavate the material over the pipe by bucketing and pumping. Approximately 4,000 cu yd of material had to be excavated to provide enough space to remove the pipe and effect repairs.

Meanwhile, pumping of local sources in Richmond was increased to the full capacity of the pumping stations. This was not sufficient to meet the demands, however, and 7 mgd had to be drawn from storage in the distribution reservoir in Richmond. The reservoir could supplement the supply from local sources for only about 60 days.

To help alleviate the emergency, steps were taken to stop waste and leakage and the public was apprised of the necessity of conserving water. Pressures were reduced by 13 psi during the day and 17 psi at night. At first, there was a 3-mgd (15 per cent) drop in consumption, but the demand gradually increased as the consumers found that there was no immediate likelihood that the supply would be curtailed.

Within a week after the break occurred, the pipe was uncovered sufficiently to permit the removal of the broken section. In order to permit a diver to enter and make repairs, it was found necessary first to enlarge the hole in the broken pipe. Cutting of the broken section for removal was done mostly from the inside by means of electric torches and was continued night and day until the work was completed and the broken pipe could be brought to the surface. This took 10 days.

While the work of cutting was in progress, designs were made and orders placed for a solid cast-steel sleeve about 5 ft long and for a split sleeve of similar length, it being expected that one of the sleeves could be found suitable to effect repairs. The solid steel sleeve was used.

The muck which had settled in the exposed ends of the pipe upon removal of the broken section was cleaned out by the divers and timber blocking was laid at the bottom of the trench to support the new pipe. The solid steel sleeve was then placed over the end of the cut pipe. A new length of flexible-joint pipe, which had been turned down to the normal outside diameter at the spigot end, was lowered in place, and the sleeve was drawn over it, closing the gap. The two sleeve joints and the flexible bell joint were then calked with lead wool.

Before the siphon was restored to service it was cleaned by introducing water from the Brooklyn end and discharging through a blowoff at the Richmond end. Chlorine was injected at the Brooklyn shore by means of a temporary connection and chlorination plant in order to disinfect the interior of the pipe, which had been subjected to contamination during repairs from the sewage-laden waters of the bay. The treatment was continued for 7 hr, after which unchlorinated water was passed through the pipeline for 3½ hr. A sample of water taken and examined at the end of this period proved to be of excellent sanitary quality. Tests showed the new joints to be tight.

A month after the break had occurred, the siphon was again in service supplying water to Richmond. Backfilling under, around, and over the main was continued for a week until a depth of about 10 ft over the pipe was secured.

Conclusion

While the siphon was under repair, 200 mil gal was drawn from storage in the Richmond distribution reservoir, depleting it to half of its capacity. Although there was no immediate danger of exhausting the supply in this reservoir, the situation caused considerable uneasiness for a time, and soon after this incident an additional 42-in. pipeline was installed across the narrows.

With duplicate feeds to Richmond, there no longer is much danger of a serious interruption of service to that borough. Contract plans are being prepared presently for constructing a 10-ft water tunnel to Richmond, to take care of the future requirements of the borough, with the population growth expected to be occasioned by the construction of a new bridge connecting it with Brooklyn. When this tunnel is completed, the two mains crossing the narrows will be kept on a standby basis and Richmond will be assured of an unfailing supply of water.

The narrows siphon incident points up the urgent need of installing dual transmission mains to isolated areas so as to assure a supply of water in the event of a break. New York provides such feeds to several islands in the East River on which hospitals and penal institutions are located.

Detroit—Gerald J. Remus

A paper presented by Gerald J. Remus, Gen. Mgr., Dept. of Water Supply, Detroit, Mich.

The Detroit Department of Water Supply provides water for Detroit and 49 adjacent communities, and contract negotiations are underway to provide service to twelve additional communities. At the present time 3,400,000 people, or 42 per cent of the population of Michigan, get their water from the Detroit system. Detroit has three major pumping stations, with the fourth under construction, and plans are already underway for a fifth major station. Water is transmitted and distributed to the system through a network of steel, asbestos-cement, reinforced-concrete-lined steel cylinder, prestressed-concrete cylinder, and cast-iron pipe, totaling more than 6,600 mi. A breakdown according to type is given in Table 1.

All water service contracts between Detroit and its suburban municipal customers require that installations must meet Detroit's standards in every characteristic. The establishment of these standards requires extreme care and sound engineering judgment. Equally important is the public relations job of winning acceptance and application of these standards. In addition, the annual repair and maintenance expenses, with service reliability, became major factors in the cost of water. Therefore, there is a twofold purpose in studying water transmission and distribution systems: to control costs and reliability, and to guide the development of an ever enlarging, reliable, and efficient water system, involving many units of government.

The Detroit Water Board maintains the mains within the Detroit city limits, and good records are available. The suburban communities maintain their own distribution systems and the Board does not have their records. Therefore, this analysis of water main troubles is concerned only with the 3,085 mi of pipe within the Detroit city limits.

TABLE 1

Types and Lengths of Detroit Area Water Mains, 1960

Type	Installed Length—mi		
	Detroit	Suburban	Total
Steel	52	3	55
Asbestos-cement	3	19	22
Reinforced-concrete-lined steel cylinder	52	80	132
Prestressed-concrete cylinder	13	24	37
Cast iron	2,965	3,420	6,385
Total	3,085	3,546	6,631

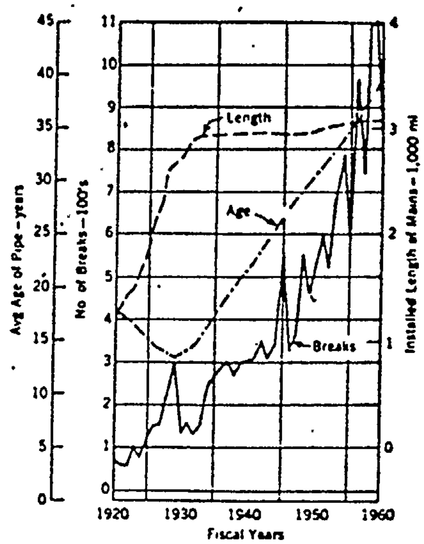

Fig. 1. Cast-Iron Main Breaks in Detroit, 1920–60

Because of the increase in the number of breaks in cast-iron mains (the total miles of main remains relatively constant), Class 150 cast-iron pipe is no longer acceptable in Detroit.

Steel Pipe

The 52 mi of steel pipe have been in service 25–30 years. Most coatings that were used were of insignificant protection, and failures due to corrosion have been in the form of leaks rather than breaks. During the period 1950–59, an average of 46.9 leaks per year has occurred in steel mains. The sizes of the mains in which trouble occurred varied from 12 in. to 60 in. Because there has been an increase in pitting and deterioration of steel pipe, the smaller sizes have gradually been replaced and the larger sizes are being prepared for relining.

Asbestos-Cement and Concrete

Asbestos-cement pipe has been in use only since 1937, and in moderate amounts. An evaluation of the merits of this type of water carrier can, therefore, be only a calculated guess at best. The performance record of asbestos-cement pipe does indicate, however, that its use will be continued and moderately increased.

Reinforced-concrete and prestressed-concrete water mains, totalling 167 mi of large pipe, have furnished satisfactory service. These mains have not faced the test of time, but the record developed thus far indicates that their use will be continued.

Cast Iron

The bulk of the 3,085 mi of main within the Detroit city limits is cast iron. This pipe has been used since 1838. Of the cast-iron pipe in service, 2,750 mi is largely of Class 150, and 215 mi is Class 250 pipe. Class 250 pipe has not caused trouble, but it has been in use only since 1941, and only in 6- to 24-in. sizes. The record of cast-iron main breaks (practically all in Class 150 pipe) is given in Table 2. The curves in Fig. 1 illustrate the total cast-iron main breaks since 1920, the average age of the pipe, and the number of miles of mains in service. The total main breaks gradually increase, and as the total miles of mains remains relatively constant, the only conclusion that can be arrived at is

TABLE 2

Record of Breaks in Detroit Cast-Iron Water Mains, 1940–60

Year Installed	6 in.	8 in.	10 in.	12 in.	16 in.	24 in.	30 in.	36 in.	42 in.	48 in.	Total
	No. of Breaks										
1940	140	152		9	1	1					303
1941	176	173		8	3	1	1			1	363
1942	147	151		18	6		1				323
1943	169	158	3	8	2	1	1	1	2	1	346
1944	206	175	3	5	3		1		3	1	397
1945	228	204		9	5		1			1	448
1946	133	167		10							310
1947	225	188		16	2	2			2		435
1948	274	275		16	2	2			3		572
1949	227	230	1	17	4	2					481
1950	260	270		9	2	6	1				548
1951	269	243		18	5	2	1				538
1952	296	255	1	13	3	2	1		1	1	573
1953	410	322	2	20	5	1		1		2	763
1954	300	322	1	19	7	1			2		642
1955	342	376	1	23	7	6	1				756
1956	405	356	5	28	4	4	1	1	1		805
1957	357	362	2	2	33	11	1	1	1		770
1958	476	459	1	30	9	4	1				980
1959	479	419	3	44	15	2	2		1	1	966
1960*	217	219		17	3				1	1	458

* Estimated for May and June.

that as time elapses the maintenance of existing mains is going to cost more and more, service of distribution system will become more unreliable, and a replacement program will have to continue.

The causes of breaks in these cast-iron water mains cannot be identified exactly. There are many related variables, such as water and ground temperature changes, thinness of pipe walls, poor construction materials and practices, water hammer, excessive street loads causing street settlement which could be amplified by shock and insufficient thickness of concrete in the roadbed, sewer washouts, inflexible pipe joints, poor soil conditions, and other utility obstructions. All of these factors affect results, but how much each should be held accountable for is hard to evaluate. Water temperature changes and substandard pipe wall thicknesses appear to be the most important factors.

Present Practices

The following precepts are now being followed in Detroit:

1. Class 150 cast-iron pipe is unacceptable, and those sections now having an excessive breakage rate must be replaced.
2. Class 250 cement-lined cast-iron pipe is acceptable, and it is the only cast-iron pipe that will be used.
3. Use of Class 200 asbestos-cement pipe will gradually be increased, and it will be allowed to prove its worth, in 6- and 8-in. sizes, and under special installation practices.
4. Class 150 asbestos-cement pipe is unacceptable.
5. Mains 24 in. in diameter in either standard cylinder pipe or prestressed embedded-cylinder pipe and mains 16 in. and 20 in. in diameter in prestressed cylinder pipe will be accepted. Specifications on each job will spell out the construction standards, however.

Conclusion

Improved laying practices of all pipe have been adopted. More flexibility in the joints and better embedding practices have been adopted, and closer inspection in the field is necessary. The specifications applied to the existent construction and improved maintenance practices will, it is hoped, keep the system under reasonable trouble control and improve reliability.

Indianapolis—*Howard W. Niemeyer*

A paper presented by Howard W. Niemeyer, Supt. of Distribution, Indianapolis Water Co., Indianapolis, Ind.

The record of pipeline failures in the Indianapolis distribution system during the period 1926–54 was reviewed in the May 1955 issue of the JOURNAL in a discussion of an article by Leo V. Garrity.[1] In his article Garrity concluded that breaks in cast-iron pipe in Detroit were caused primarily by a combination of temperature stresses imposed by the restraint of sulfur compound joints and a progressive loss of pipe strength from corrosion. Although Indianapolis at that time was experiencing only three pipe breaks per year per 100 mi of main, compared to 20 in Detroit, analysis of those failures did lend support to Garrity's conclusion. The experience with pipeline failures since 1954 has provided additional supporting information, and it now appears that more than half of all the failures that have occurred in pipe and joints in the Indianapolis system over the past 10 years can be directly associated with the use of sulfur compound as a jointing material. Experience has also indicated that centrifugally cast pipe in 18-ft lengths has not performed as well as pit-cast pipe in 12 ft lengths, both being laid with sulfur compound joints.

Indianapolis System

To evaluate the Indianapolis experience properly, the physical characteristics and certain environmental conditions of the system need to be known. The water supply for the city comes from a surface source, except that well fields formerly used have been maintained for emergency purpose. Water

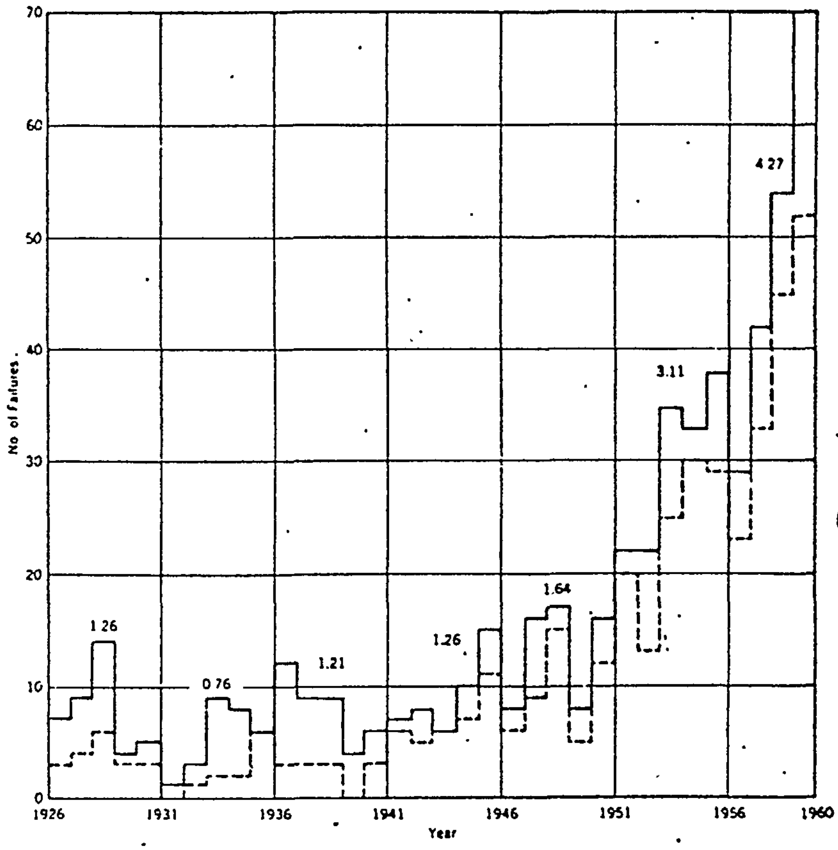

Fig. 2. Cast-Iron Main Failures Other Than Those Caused by Accidents or Freezing, 1926–59

The dashed curve represents that portion of the failures that was caused by circumferential breaks. Figures accompanying the curves represent averages per 100 mi of main per year.

temperature, therefore, has a seasonal variation which amounts to as much as 50°F between winter and summer. During prolonged cold waves, water temperature approaches 32°F. Ground frost penetration has varied over the years from a slight crust to as much as the 54-in. depth that was reached in the severe 1935–36 winter, the maximum penetration on record. The soil is for the most part clay, and, in general, there has been little evidence of corrosive action on the exterior of pipes, except in some isolated cases. It has rarely been necessary to install mains over filled ground. Cast-iron pipe has been used throughout the system, except for some bridge crossings and recently installed large feeder mains. The schedule of material types used is shown in Table 3.

TABLE 3

Types and Lengths of Indianapolis Water Mains, 1924–60

When Installed	Type	Class	Section Length ft	Jointing Material	Installed Length mi
Before 1924	pit cast	B*	12	lead	482
1924–38	pit cast	B*	12	sulfur	187
1938–50	centrifugally cast; unlined	150	18	sulfur	191
1950–60	centrifugally cast; lined	150	18	rubber	352

* Class C or D used in large transmission mains.

Mains were installed with 48-in. cover prior to the 1936 frost and 54 in. ever since. Installations have always been made in conformance with the best construction practices known with respect to pipe inspection and handling, trench conditions, and clearances with other structures. Service connections have been installed in a manner to avoid stresses from this source. Average distribution pressure is maintained near 55 psi with some maximums of 120 psi occurring in limited areas adjacent to one high-level pumping station and some of the boosters. The system has been successfully operated to avoid water hammer.

Pipeline Failures

In spite of the care used in constructing and operating the system, miscellaneous failures have occurred as a result of some occasional material and construction faults and because of conditions that have developed beyond control of the distribution engineers. Over the years the number of such failures has not been considered excessive; they were, therefore, accepted as normal operating problems. An increasing incidence of failure since 1940, however, has indicated presence of some factor or factors that apparently did not exist previously. The reason for any one failure is seldom obvious, and as it has been neither economically feasible nor practical to investigate each job for all factors present, no record of failures by cause has been accumulated for study. Much can be learned, however, by examination of job records as to the kind of failures that have occurred and the types of materials involved.

The quantitative record of pipeline failures during the period 1925–59 is summarized graphically in Fig. 2, showing pipe breaks, and Fig. 3, showing joint failures. These records exclude accidental damage to the system by adjacent construction and show only those failures from normal causes. The exclusion is not intended to underrate the problem of damage failures which create emergency situations, disrupt normal operating patterns, and create added work loads for maintenance personnel. In the Indianapolis system, where damage has probably been no more extensive than drant in place of the solid-barrel type has been one solution to this problem.

The reader's attention is directed to the relatively small number of pipe breaks prior to 1941 (Fig. 2). In this early period of the record the incidence of pipe failures averaged only little more than one break per year per 100 mi of main—certainly a favor-

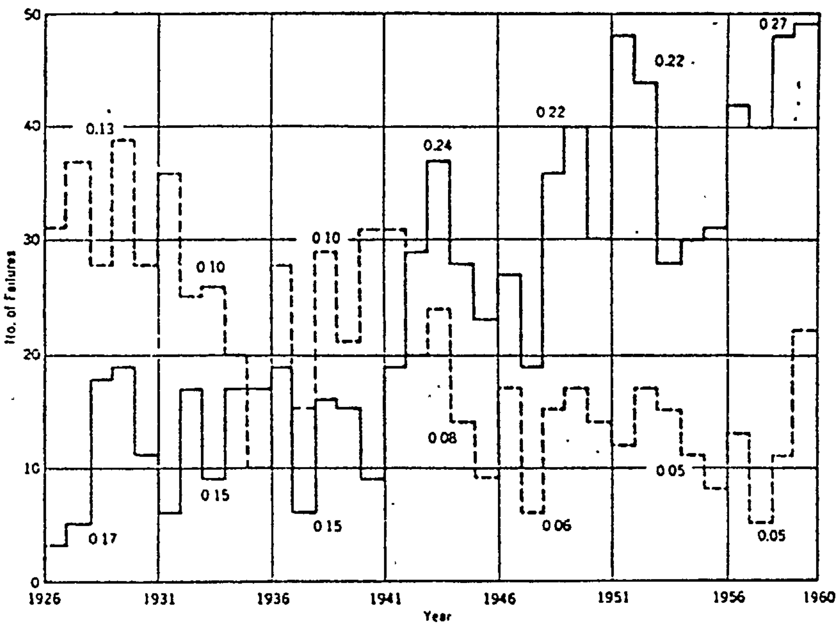

Fig. 3. Joint Failures, 1926–59

The solid and dashed curves represent failures of sulfur compound and lead joints, respectively. Figures accompanying the curves represent averages per 1,000 joints per year.

in other systems, construction activity, largely for sewer construction, has been responsible for 223 pipe breaks and sixteen joint failures in the past 10 years. Also omitted from the records in Fig. 2 and 3 are nineteen emergency situations created by pipe breakage in hydrant leads from automobile collisions. The use of the breakoff hy-

able record. There were no circumferential breaks in the years 1931 and 1939. The absence of any effect of severe winter temperatures on the incidence of breaks is to be particularly noted for the years 1936 and 1940. Since 1940, however, the incidence of pipe failures has steadily increased to a high of six failures per 100 mi of main in 1959, or six times the average prior to 1941. This increase has been almost entirely due to circumferential breaks which have accounted for 78 per cent of all breaks in the last 10 years. Other kinds of pipe failures have held a rather consistent relationship with miles of mains, amounting to an average of only about one per year for each 200 mi. An increase in the latter types of failures did occur in 1959 because there were nine instances of hole development in pipe from corrosion. The corrosion was later found to be the result of electrolysis in the vicinity of rectifier stations installed by the telephone company for cathodic protection of their underground cables, which paralleled the water main.

Jointing Materials

Figure 3 shows the performance of jointing material, for joint failures share equally with pipe breaks in the maintenance problems of distribution systems. It can also be shown that sulfur compound failures can be related to the temperature stresses imposed on pipelines by their restraint. No rubber gasket joint failures are recorded, as the trouble experienced with this type of joint has been very limited and has invariably resulted from improper tightening of the bolts in mechanical joints at time of installation. There has been no instance of mechanical-joint failure from corrosion of the bolts, although some of the bolts uncovered have shown evidence of galvanic action. Also excluded from the record are instances of rubber gasket joint failures on hydrants, bends, and other fittings if thrust blocking has shifted, permitting a joint to slip. There is a need for some simple and effective means to provide positive joint restraint where thrust blocking is required. The use of kicker blocks behind fittings is a crude and sometimes awkward method of countering thrust. Indianapolis is currently using stud type follower rings in addition to blocking on the mechanical joints of fittings as added assurance against thrust failures.

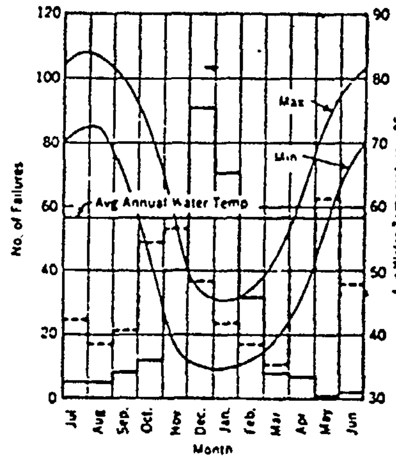

Fig. 4. Pipeline Failures by Month of Repair, 1950–59

The solid and dashed curves represent circumferential pipe breaks and failures in sulfur compound joints, respectively. As can be seen, circumferential breaks appear to occur during periods of low temperature, whereas joint failures occur during periods of rapid temperature change.

Joint failures have outnumbered pipe breaks in Indianapolis two to one in the past 10 years. Sulfur compound has been responsible for 75 per cent of joint failures, although only 35 per cent of all joints are of this material. It is interesting to observe from Fig. 3 that lead joints, which have the greatest age, are showing a decreasing incidence of failure, whereas sulfur compound failures have been increasing. The seasonal pattern of both sulfur compound failures and circumferential breaks indicates a relationship of failure to water temperature. By plotting such failures by month of repair and superimposing water temperature curves on the graph as shown in Fig. 4, one can see a rather fixed relationship. A similar plot of other types of pipe breaks failed to produce a similar relation. Lead joint failures so plotted did show a somewhat frequency curve would probably be much more pronounced if the months of failure were known and used for this record rather than months of repair. Nevertheless, the relationship of failures to temperature is sufficiently clear to establish that the longitudinal stresses in pipelines imposed by restraint of sulfur compound are a cause of its poor performance. It is felt that material fails under fatigue of repeated stressing.

Again, in Fig. 4 the circumferential breaks are shown to start occurring

TABLE 4

Indianapolis Main and Joint Failures by Size and Material, 1950–59 *

Size in.	No. of Circumferential Breaks					No. of Joint Failures		
	Pit-Cast Pipe			Centrifugally Cast Pipe		Lead	Sulfur	
	Lead Joint	Sulfur Joint	Screwed Joint	Sulfur Joint	Rubber Joint	Pit-Cast Pipe	Pit-Cast Pipe	Centrifugally Cast Pipe
2¼			20					
4	11					24		
6	31	8		148	17	25	43	28
8	10	5		18	1	9	37	10
10						7	1	
12	2			3		16	94	24
16	3					15	71	15
20	3					9	52	6
24–36	1					23	9	
All sizes	62	13	20	169	18	128	307	83

* Comparison should be made with Table 5.

higher incidence when water temperature was approaching its minimum, although not in a pronounced pattern.

From Fig. 4, it can be seen that sulfur compound failures have two peak periods of occurrence, in spring and fall when the water temperature is approximately at the annual mean. Minimum frequency is first at the maximum water temperature and then again after the minimum level has been passed. The peaks and valleys of the when water temperature falls to 40°F and to reach peak frequency when it is at 34°F or less. On several occasions when relief from high frequency has been desired, breaks have been stopped completely by the addition of well water to the surface supply, thus raising the water temperature by 4° or 5°F. This stoppage has been achieved regardless of the depth of frost penetration. It must, therefore, be concluded that longitudinal stress created by temperature change has been a primary cause of circumferential pipe breaks during the past 10 years. As there is no evidence of cold-weather effects on the incidence of pipe breaks prior to 1941, it is necessary to analyze the records further to find factors that were not present at that time.

Comparison of Materials

From a classification of circumferential breaks and joint failures by sizes and types of materials (Tables 4 and 5), a difference in performance of materials in pipelines can be noted. It is significant that 85 per cent of the breaks has been in the 6- and 8-in. sizes and that 70 per cent of these has the same percentage of total mains as the centrifugally cast pipe. The difference in the performance of the two types of pipe with the same jointing material must be attributed either to the difference in wall thickness or to the longer joint spacing of the centrifugally cast pipe, or to both. In comparing the performance of the sulfur compound installed in these two types of pipe material, it is found that 32 per cent of its failures in 6- and 8-in. sizes occurred in the centrifugally cast pipe and 68 per cent occurred in the pit-cast pipe, even though the shorter length of the latter reduces the longitudinal stress to be absorbed by each joint by one-third.

TABLE 5

Pipe and Joint Failures by Material, 1950–59

Type of Pipe	Type of Joint	Avg Length of Mains in Service mi	No. of Breaks per 100 mi.	Avg No. of Joints in Service *1,000's*	No. of Failures per 1,000 Joints
Pit cast	lead	482	12.9	241	0.53
	sulfur	187	7.0	94	3.27
	screwed	5	400.0		
Centrifugally cast	sulfur	191	88.5	74	1.12
	rubber	159	11.3		

occurred in the unlined centrifugally cast pipe laid with sulfur compound joints, although the combination of materials represents less than 19 per cent of the total mains in the system. There was a high incidence of sulfur compound failures in the larger sizes of pipe of this construction, although there was a complete absence of pipe breaks. It is also significant that only 5.5 per cent of the breaks have been in the pit-cast pipe laid with sulfur compound joints, even though the pipelines made of this combination of materials have been in service an average of 13 years more and represent about

Beam Action

It is recognized that beam action or cantilever action stresses of varying degree have attended many of the circumferential breaks and have contributed to their incidence. On the other hand, in a great many of these breaks the ruptured ends of the pipe have opened up as much as ¼-in. with the ends remaining in perfect alignment, indicating absence of deflection and the presence of contraction only. Aside from the influence of beam action, the record does indicate that the centrifugally cast pipe laid with sulfur compound joints has not satisfactorily withstood the longitudinal stress from temperature change and has contributed heavily to the Indianapolis record of failures. The rising incidence of failures would indicate either a progressive loss of pipe strength from corrosion or failures from metal fatigue. The pit-cast pipe appears to have failed from beam or cantilever action, and its joints have failed from longitudinal stress.

Age of Pipe

With regard to failures in the pit-cast pipe laid with lead joints, it should be pointed out that these mains range in age from 35 to 80 years. This early pipe was not manufactured with the quality control that has been used in more recent years. It has been subject to tuberculation and whatever external corrosive conditions have existed, especially some known electrolysis in the days of streetcars. This pipe is all contained in the central and oldest part of the city where many of the streets are crowded with every possible type of utility structure. Many of the other utility lines lay over or under the water mains and they have not always been installed with proper clearances. Under such conditions, an incidence of slightly more than one circumferential break per year in each 100 mi of old mains is not surprising.

Other Factors

The use of the rubber gasket joint has eliminated horizontal stressing from temperature variations, and will help to avoid failures. The use of cement lining will eliminate the loss of pipe strength by internal corrosion. These improvements, however, will not prevent failures caused by other factors. The incidence of circumferential breaks in centrifugally cast pipe with rubber gasket joints has been shown (Fig. 3) to be much lower than in the same pipe with sulfur compound joints, but not so low as in pit-cast pipe with sulfur compound joints. It must be recognized that an 18-ft length of 6- or 8-in. pipe is a reatively poor beam and will fail under abnormal beam action stresses. It must also be recognized that such abnormal stresses will naturally develop from changing conditions in a system and are beyond control of the utility. A trouble-free system can, therefore, be attained only by providing allowances for such stresses. Heavier wall thickness, shorter lengths, or a more ductile iron, at least for the smaller diameter pipe, may provide a desirable improvement. Ductile iron appears to be more desirable, as it not only provides the needed elasticity and deflection limits, but also resists impact damage in pipe handling and from accidents.

Economic Considerations

Economic considerations have obviously had much bearing on the design of pipelines for distribution systems. Installation savings, however, are only temporary economies, if they result in a high incidence of failures. The property damage that frequently results, the unscheduled disruptions to customer and fire protection services, the cost of repairs, and the hardship imposed on maintenance personnel who must frequently work long hours under most adverse weather conditions are adverse consequences of water main failures. The distribution engineers must decide if the failure experiences in any one system justify the cost of improved materials.