Which Pipe Could Break Next?

Assessment methods to predict future water main breaks

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The image above shows a ductile iron pipe that was located along a coastal area in New England. Installed in 1975, the pipe lasted only 30 years.

Approximately 850 water main breaks occur every day. These breaks cause millions of dollars of damage and have a detrimental impact on distribution systems, roadways, and water customers. This paper will address the main causes of water main leaks and breaks and how water systems can proactively pinpoint the next potential break before it happens. In addition, three levels of pipe analysis will be examined: a high-level view of water systems using the IWARP tool to predict the number of water main breaks; a bottom up approach that looks at individual pipes by reviewing data collected on New England pipes over the last seven years including information on material, size, age, and break history; and pipe crushing actual samples obtained in the field. This paper will review the data collected and the results of crushing over 200 samples of pipe collected in New England.

Why Mains Break

Water mains break spontaneously for three major reasons: excessive load, temperature, and corrosion. Water mains also break due to construction activities, but these breaks are not due to compromised or aging pipe, and will therefore not be examined in this paper.

Excessive loads on the pipe occur when the internal or external forces on a pipe exceed the actual strength of the pipe. Reduced strength of a pipe can sometimes be caused by poor design. Manufacturers generally incorporate a 2.5 factor of safety into the pipe, which means that the pipe can withstand a load that is two and a half times the break load. Corrosion, the causes of which are documented below, is a major factor in reduced strength of a pipe. Internal excessive forces include water hammer, while external excessive forces include truck loads, poor bedding, and frost heaves.

Temperature affects water mains, particularly in areas with continental climates such as the northeast. In these locations, ground temperatures fluctuate 30-40 degrees between winter and summer, depending on whether the area is in the shade or in the sun. Additionally, water temperature running through the pipe varies from season to season, although to a lesser degree than soil temperatures. Ground temperature variations can cause increased tensile stress on the water main. Additionally, as temperatures drop, moisture in the soil expands, generating additional forces on the main.

Corrosion is a major factor in water main breaks. Corrosion weakens the pipe wall which reduces the strength of the pipe to withstand external or internal forces. Poor soils, such as peat and clay or soils with high organic content or corrosive materials such as cinders in roadways or old landfills, can be significantly corrosive on certain types of water main including cast iron and ductile iron. In addition, high groundwater and stray currents are major contributors to external pipe corrosion. Poor water quality, such as water with excessive iron or water with a low pH, corrodes the interior of unlined pipe.

Pipe corrosion is caused by many factors

IWARP

Individual Water Main Renewal Planner (IWARP) was developed by the American Water Works Association (AWWA) and the National Research Council of Canada as a predictive model that attempts to locate patterns of main failures within a water system, providing projections of water main failures up to 30 years into the future. The program runs in Microsoft Excel and uses Microsoft Access data tables. This statistical model uses static factors such pipe material, size, age, and soil type, as well as dynamic factors including changes in climate, pressure, and cathodic protection. The model does not indicate precise locations of breaks; rather, it provides an overall assessment of the system and the estimated number of breaks likely to occur in the future, allowing for better financial planning. The quantity and quality of the data input into the model directly drives the accuracy of the results. If a system has little data or only experiences a few breaks per year, the forecast of breaks may not be accurately modeled. Therefore, the model is best for water systems with ten or more breaks per 100 miles of main per year.

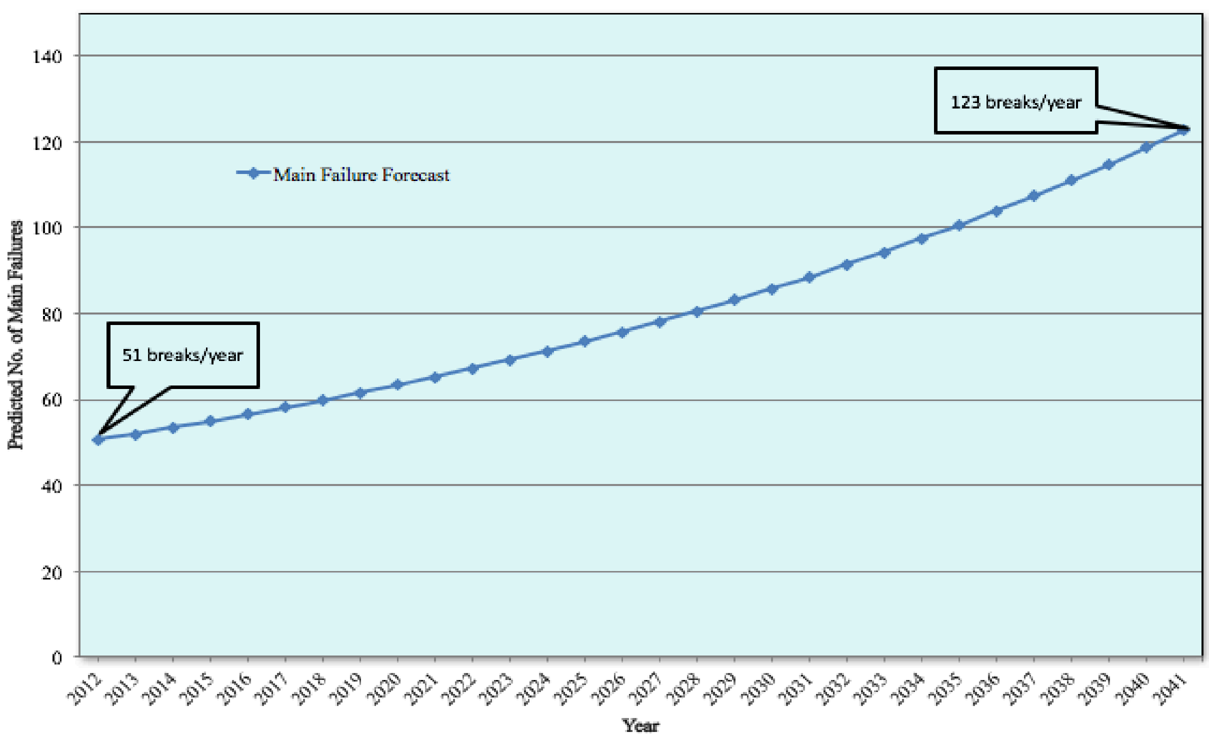

Figure 1: IWARP Main Failure Forecast

Figure 1 shows an example of one community with approximately 500 miles of pipe analyzed. The input data was extensive, including detailed break history that reported type of break, location, and material. The pipe data was partitioned based on installation year and by certain pipe materials. A forecast of breaks was developed; however, the total number of breaks compared to the total length of pipe analyzed could not provide a statistically accurate correlation. It did provide some insight on potential breaks and, therefore, this community benefited from better capital planning.

Data Collection

Data collection is a critical part of estimating the condition of water mains. Tata & Howard's asset management program includes collected data for over 25 New England communities, which equates to approximately 5,000 miles of pipe. The database includes information on breaks, diameter, pipe materials, installation year, and soils, as well as information on pressures, water hammer potential, and water quality. The information obtained from the various water systems is current conditions; therefore, if a pipe broke and was replaced in its entirety, the break history on the older pipe was not captured. The database will be progressively backfilled with information on all breaks, whether replaced or not, which will strengthen the results.

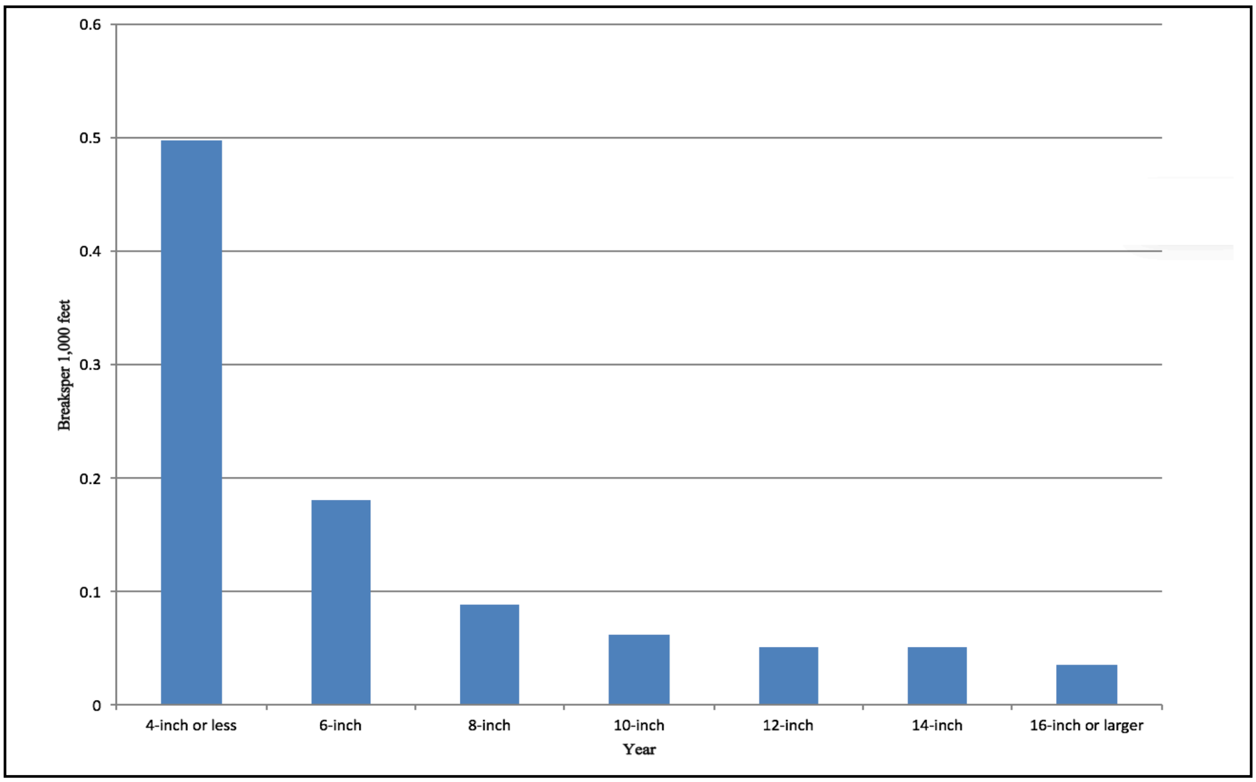

Figure 2: Main Failure by Size

Figure 2 shows main failure by size. Based on the available data, breaks have been plotted by size per 1,000 feet of main. The data indicates that smaller mains fail more frequently than larger mains and that, in general, as the diameter of a pipe increases, the strength also increases, primarily because of bending forces on the pipe. Pipes that are six inches in diameter or less are more likely to deflect or bend than a larger diameter main. Pipes that are eight inches in diameter or greater are less likely to break from bending forces due to their larger diameter and resulting increased moment of inertia.

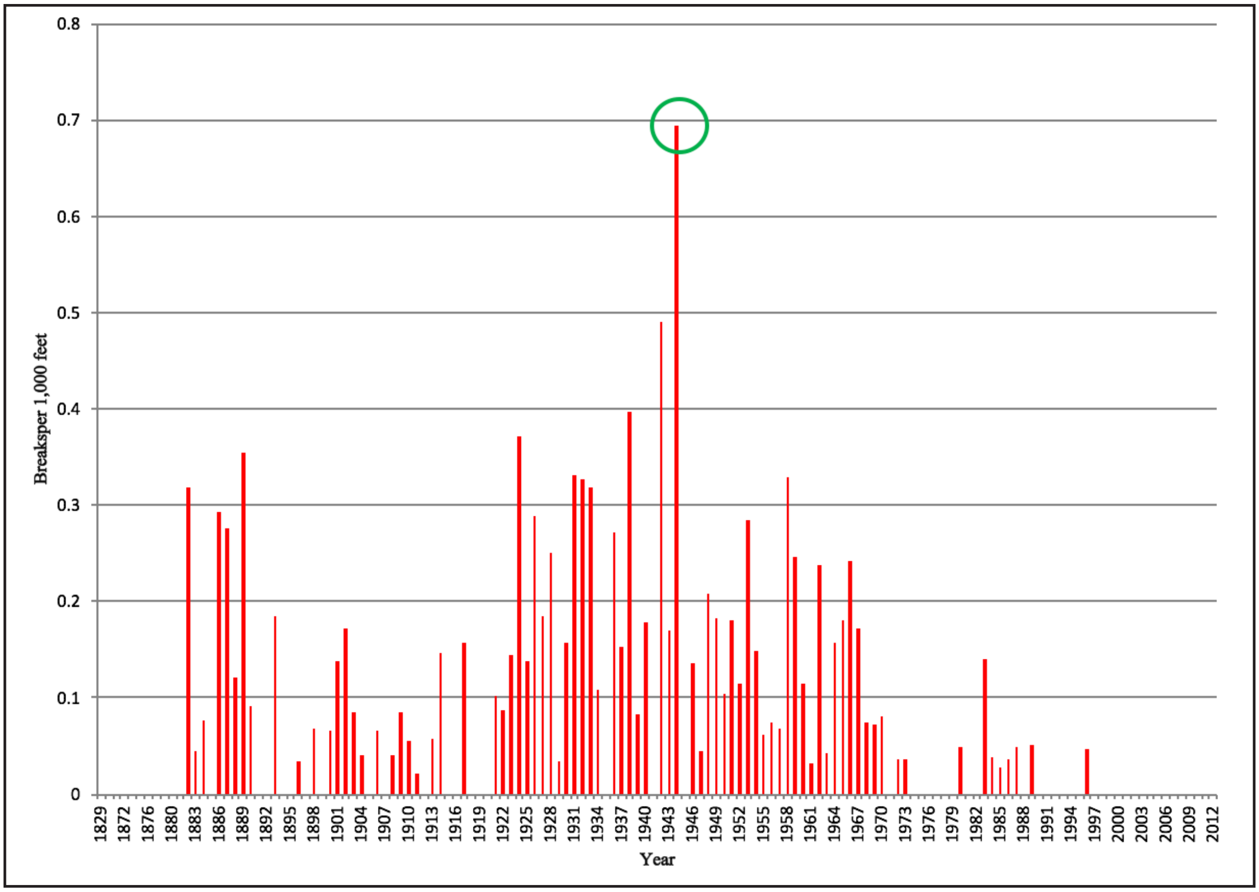

Figure 3: Main Failure by Installation Year - Sample Community 1

Figure 3 shows one community's break history per 1,000 feet of main. This community has over 500 miles of pipe and generally good records. It is apparent that the mid-1940s pipe is a major problem in this community.

Figure 4 shows a sample community with over 1,500 miles of pipe and very good break data. The mid-1940s pipe is also a problem in this community; however, mid- to late-1920s and late-1960s into 1970s has been more problematic. While the two systems are similar, they are not identical, indicating that pipe condition varies greatly among states, communities, and even streets.

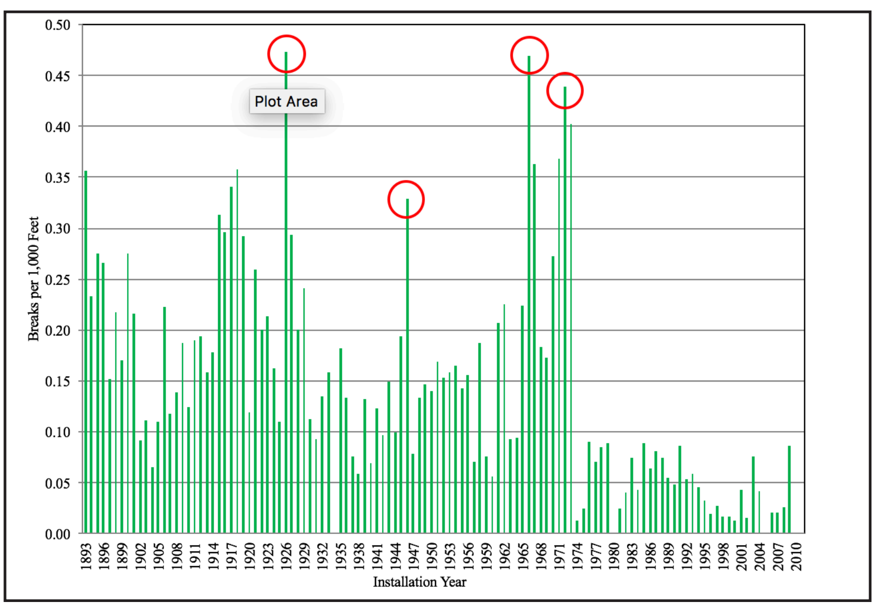

Figure 4: Main Failure by Installation Year - Sample Community 2

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Figure 5 shows examination of all types of pipe including cast iron, asbestos cement (AC), ductile, and polyvinyl chloride (PVC) from the entire database of 5,000 miles of pipe. Note the 1933 pipe with significant breaks per 1,000 feet of main as well as the 1923 to 1926 pipe. The mid-1920s to mid-1930s has been a known time frame for problem pipe throughout the northeast, regardless of soil conditions. Also of note is the 1915-1916 pipe with a significant number of breaks. During WWI, iron was predominantly used for war efforts instead of water pipe, which reduced the thickness of the pipe wall. A similar event occurred in the mid-1940s during WWII. The beginning of the 1950s marked the transition from unlined cast iron to factory lined cast iron, and 1966 marks the general time frame when most of New England was starting to switch from cast iron to ductile iron.

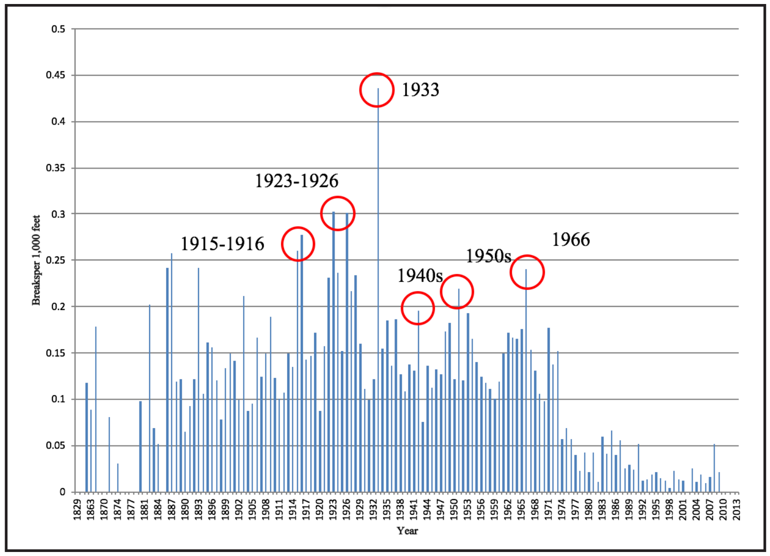
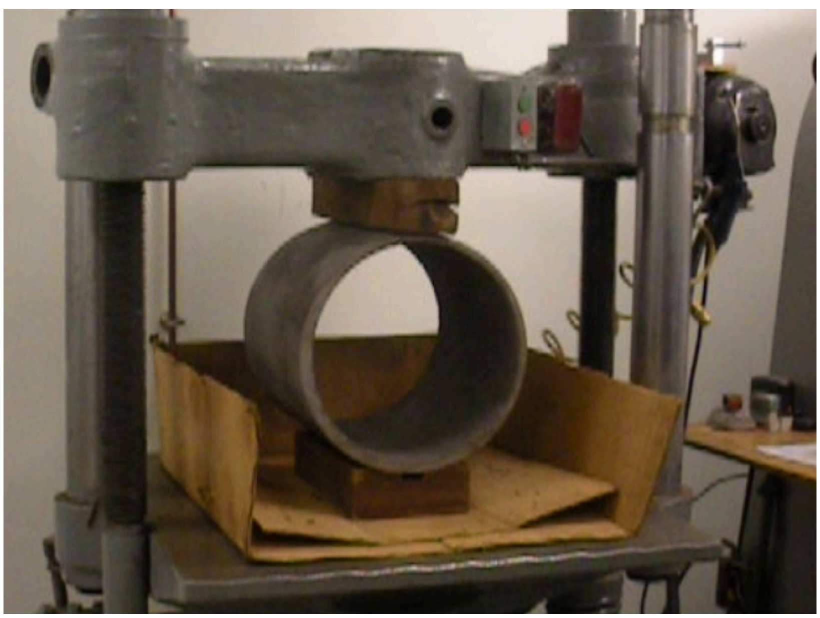


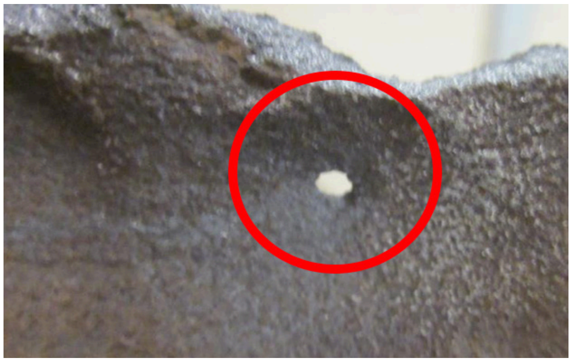
Figure 5: Main Failure by Installation Year - All Break Data


The ring test method is used at a qualified testing laboratory to obtain the current break load for the pipe. Pictured is a 12-inch pipe being crushed.

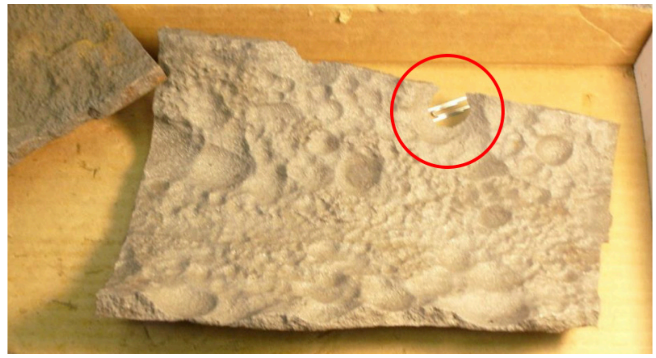
Condition Assessment

Condition assessment includes an evaluation of a sample pipe extracted from the field. The process includes an inspection of the pipe after sand blasting for defects, pits, corrosion, holes, and other contributors to potential failure. If not already known, the class of pipe is estimated based on wall thickness, nominal diameter, and installation date. The pipe is then crushed, after which the remaining factor of safety can be calculated.

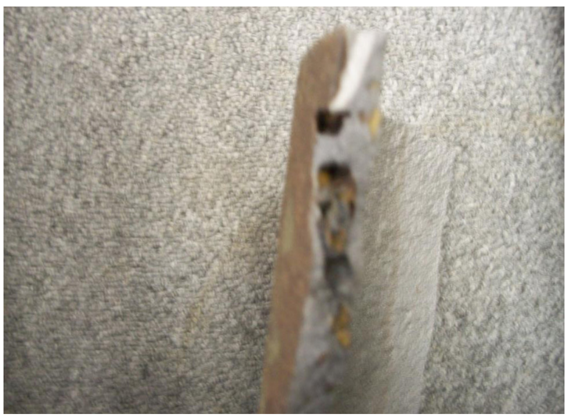
Cast iron pipe manufacturers incorporate a 2.5 minimum factor of safety (FOS) to the crushing load necessary to break a water main. Using the estimated pipe class of the water main sample, the manufacturer's crushing load with a 2.5 FOS can be compared to the crushing load that was measured at the materials testing facility, yielding the estimated remaining FOS of that water main sample. Remaining FOS values are used to assist a utility in the decision to rehabilitate a water main or schedule the main for replacement.



Wall perforation or hole in the pipe.



Corrosion in the pipe showing extensive pitting as well as a point where the pit went all the way through the pipe.



Air inclusion, or air trapped within the wall of the pipe during the manufacturing process, reduces the overall strength of the main and makes it more prone to leaks and breaks. Pit cast mains may have air inclusions.

Manufacturers would stamp the pipe with the lot number or year manufactured. This actually becomes a stress point in the main and could result in breaks.

In addition to estimated FOS, it is imperative to make careful visual inspection of the pipe. The pipe should be sandblasted to remove all dirt and tuberculation, allowing for a more detailed examination of the condition of the pipe. All samples are visually inspected for extensive corrosion on the inside or outside of the pipe, perforations that extend through the wall, air inclusions in the pipe, and any stamps or defects in the pipe.

Over the past few years, Tata & Howard has crushed over 150 pipe samples in Massachusetts and Connecticut. Samples obtained in Connecticut were part of a program that tested water mains prior to rehabilitation, while many of the samples in Massachusetts were taken after a water main break. An unbroken, one-foot sample adjacent to the break was generally obtained for testing. Therefore, the data obtained may be skewed due to known pipe failures. General recommendations for estimated FOS are as follows: over 2.5 FOS is a candidate for rehabilitation and in good condition; between 1.75 and 2.5 FOS is fair condition; and less than 1.75 FOS is poor condition.

Figure 6 shows data for 6-inch diameter pipe that was crushed. The pipe samples had varying classes and therefore, varying wall thicknesses. It shows many of the FOSs less than 1.75 are from the early part of the century, which is not representative of the break history data presented earlier.

Figure 7 shows data for 8-inch diameter pipe that was crushed. The pipe samples also had varying classes and therefore, varying wall thicknesses. It shows many of the 1950s pipe is in good to fair condition while again, the pipe in the earlier part of the century is close to a 1.0 FOS.

Figure 8 shows data for pipe of 12-inch diameter and greater that was crushed. Data shows that the mid-1940s is a problem pipe; however, this pipe had failed. The data indicates that as the diameter increases, the strength of the pipe increases, which corresponds to the break data by diameter previously discussed.

Conclusion

While there is some skewing of data due to failed mains, the collected data indicates that the oldest pipe in the system is not necessarily the weakest despite the information obtained during crushing. Some of the pipe tested from the 1800s was in better condition than pipe manufactured during later periods. Regardless of pipe age, corrosive soil typically causes mains to fail more quickly. Soil conditions such as high groundwater, peat or clay, locations near old landfills, or areas with cinders used in the roadway will degrade the exterior of a pipe and cause the main to fail. Because soil varies greatly across states, towns, and even streets, pinpointing where the next break will occur is difficult on a global analysis. However, it has been shown that there are certain vintages of pipe that are problematic regardless of soil conditions or location, including pipe manufactured during either WWI or WWII as well

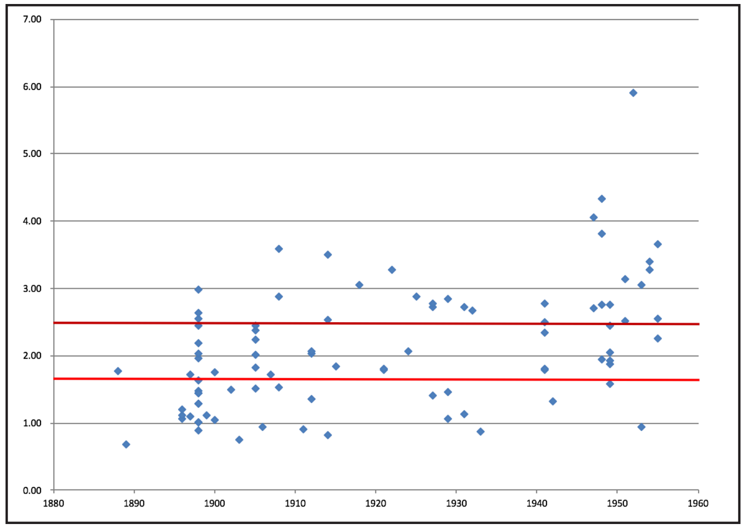


Figure 6: Remaining FOS – 6-inch

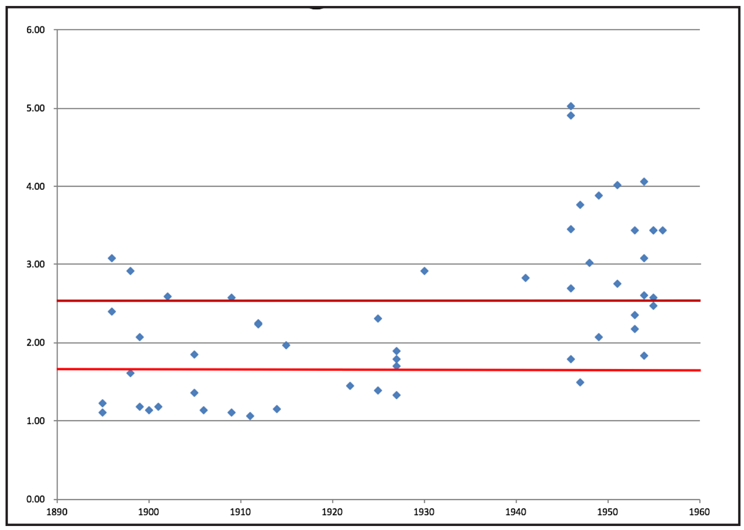


Figure 7: Remaining FOS – 8-inch

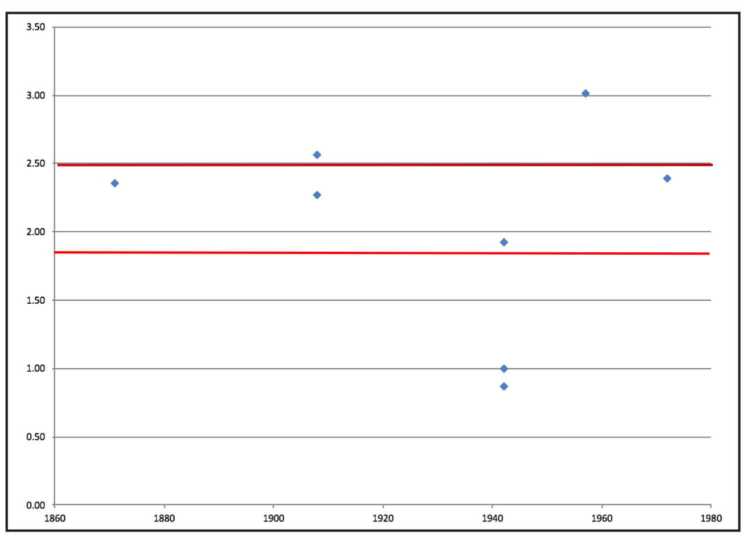


Figure 8: Remaining FOS – 12-inch

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as during the late 1920s to the early 1930s. Every system is different, with different operating pressures, soils, coastal proximity, and other water features that may be detrimental to the condition of a pipe. To fully evaluate New England as a whole, additional data is required to determine any trends in breaks. The 5,000 miles of pipe analyzed in this study is only a small sampling of the total pipe in New England. In addition, more data is needed on pipe crushing, including not only pipe that has broken, but also pipe that has not broken. This additional data may come from a sample at a connection point with a new main and an old main, installation of a new hydrant, or other activity that would minimize cost as well as the effect on water customers. This additional information will provide better estimations on which pipes require rehabilitation or replacement, whether on a global or system specific level.