A RECENT SURVEY OF WATER MAIN FAILURES IN THE US AND CANADA

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SHORT SUMMARY

A recent survey again confirms that PVC pipe has the lowest break rate when compared with break rates of ductile and cast iron, asbestos cement, steel, and concrete pipe. Other results of interest to water utilities and engineers are discussed.

KEYWORDS *Break rates, survey, PVC, water mains*

ABSTRACT

During 2017, Utah State University conducted a survey of utilities across the US and Canada to obtain data on water main failures of municipal and private water supply systems. In 2012, a very similar survey was conducted by Utah State University and presented in the 2012 Plastic Pipes Conference in Barcelona[1]. The 2012 survey showed that PVC had the lowest break rate when compared with asbestos cement, concrete, ductile iron, cast iron, and steel pipe materials. After six years, it was time to complete a similar survey that could examine any changes and current trends with respect to water main break rates. The latest survey had a greater participation rate than the 2012 survey and is believed to be the most comprehensive water main break survey ever completed in the US. The results of the latest survey again demonstrate that the break rate for PVC pipe remains the lowest break rate material when compared with asbestos cement, concrete, ductile iron, cast iron, and steel pipe materials. The latest survey also shows that break rates of cast iron and asbestos cement pipes have significantly increased and utilities should increase replacement rates of those materials. A number of other results are discussed including typical operational parameters of utilities, installation techniques, soil corrosivity effects, material inventory data, and other items that will be of interest to manufacturers, designers, and water utilities.

INTRODUCTION

During 2017, Utah State University conducted a survey of utilities across the USA and Canada to obtain data on water main failures of water supply systems. The study was comprised of two parts: a basic survey and a detailed survey. The focus of the basic survey was to examine the number of failures utilities were experiencing and how those failures related to the pipe materials used and the age of the failing pipes. This effort focused on water supply mains (sewer and force mains and pipes with diameters under 3 inches were excluded). A variety of pipe materials are used in water supply systems and over the past 100 years the materials have evolved with different manufacturing technologies. As a result, pipe performance has changed. A goal of both the basic and detailed surveys was to look at which materials were performing best at a snapshot in time and to track how pipe age affects failure rates. The focus of the detailed survey was to obtain additional utility operational characteristics, pipe age and size, multi-year failure data, and applications of trenchless technologies.

THE METHODOLOGY

The primary method used to distribute the surveys was email. A subcontractor experienced at mass emailing was utilized along with multiple email lists. Initial emails were sent to personnel at water utilities during April through June of 2017. We will refer to the survey results herein as the 2018 study to correspond with its date of publication. Participants were given links to both the basic and detailed surveys and requested to complete both, or at a minimum, completing the basic survey. Follow up phone calls were also used to encourage participation. The basic survey participants were asked for data from a previous 12-month time period and thus the results represent a time period that mostly coincides with the years 2016 and 2017.

A total of 308 utilities responded to the basic survey. Of those, 281 utilities were able to provide water main break data in the basic survey and 98 responded to the detailed survey. The survey conducted in 2012[2] had 188 respondents and thus the current survey has a 49% increase in respondents. This comprehensive study covers 274,504-km of pipe with water main break data and serving over 52.4 million people. An additional 27 utilities responded with partial data but are not included in the 274,504-km total to simplify this report. This survey is estimated to cover 14.5% of population and 12.9% of the total length of water mains in the US and Canada. Thus, the survey sample size is significant and therefore can provide reliable results. The detailed survey had a total of 98 respondents and included 157,872-km of pipe.

The USA and Canada were divided into nine regions and the 281 basic survey respondents were categorized according to the region and the size of the utility based on amount of pipe. Figure 1 illustrates the regions for this study and Table I breaks down the number of respondents by region. Acceptable participation was achieved from all regions. This is believed to be the largest survey ever conducted in the US collecting water main break data.

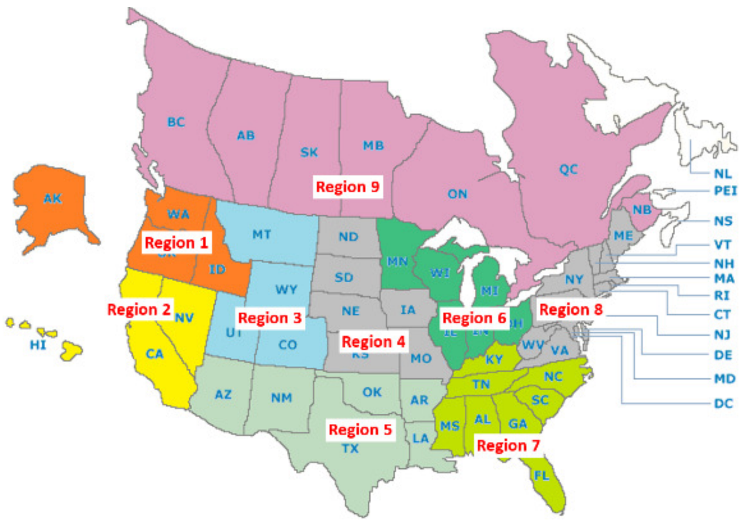

Figure 1. Regions used to report survey results.

Table I. Survey respondents by region.

Region	Number of Respondents Basic Survey	Detailed Survey
1	18	9
2	33	10
3	14	6
4	24	7
5	44	18
6	64	21
7	28	8
8	35	9
9	21	10
Total	281	98

Figure 2 illustrates the length of pipe from each region.

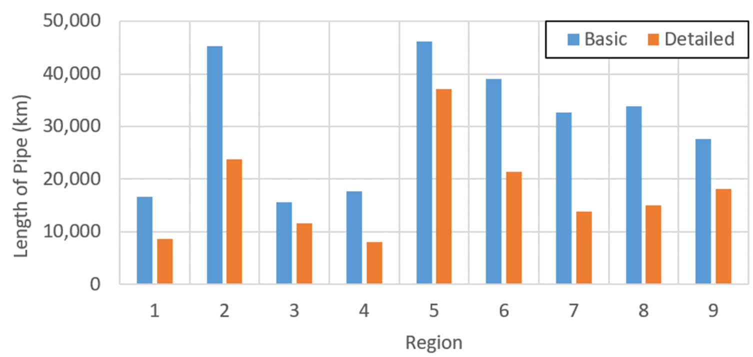

Figure 2. Pipe length (km) from each region.

The average utility size in the basic survey had 977-km of installed pipe and served a population of 186,752 and thus on average 191 people were served by every km of water main. It was desired that the survey covers small to very large utilities. Figure 3 illustrates the total length of pipe broken down by four utility sizes as well as the number of respondents to each group. Figure 3 shows that in terms of total pipe length, small to large utilities were represented.

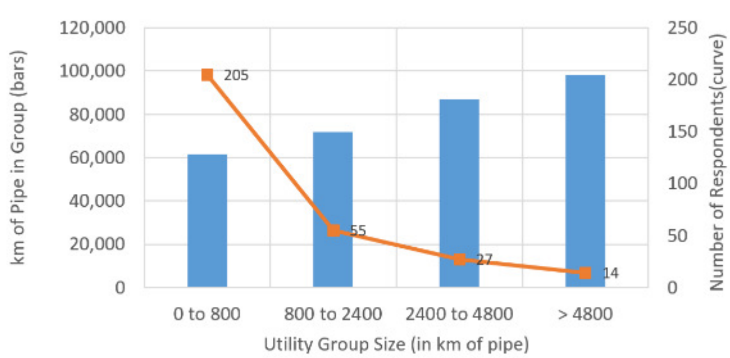

Figure 3. Pipe length of four utility size groups.

Table II lists the pipe materials and their abbreviation used in this paper. Many pipe products have evolved over the years of use, and most pipe products could be broken down into subcategories based on pipe manufacturing and surface treatments. These changes along with new installation techniques should affect life expectancy of the pipe. Both the basic and detailed surveys were intended to be relatively simple to complete and thus, encourage wide scale participation of the water utilities. Most utilities have limited records as to which specific pipe materials were installed decades ago and what corrosion protection measures were used. Therefore, tracking subcategories of material types was not completed as part of this study.

Table II. Material and their abbreviations.

Abbreviation	Description
AC	Asbestos Cement
CI	Cast Iron
CSC	Concrete Steel Cylinder
DI	Ductile Iron
HDPE	High Density Polyethylene
PVC	Polyvinyl Chloride
PVCO	Oriented PVC
Steel	Steel

PIPE MATERIALS IN USE

Figure 4 illustrates the percentage of the total 274,504-km length of pipe broken down by pipe material. The "Other" category in Figure 4 includes materials such as copper, FRP, and some galvanized steel. It is noted that galvanized steel was reported in both the steel and other categories by participants, which was unfortunate. Because there is so little HDPE (0.5%) and PVCO (0.05%) pipe in this survey, it was decided to include these two pipe materials in the "Other" category for the remainder of this paper. If there are only small amounts of a pipe material utilized, break rates can be highly inaccurate because of large scatter in the data. It is significant to consider that over 91% of the water mains are made from asbestos cement, cast iron, ductile iron, and PVC materials. This is consistent with earlier studies[3].

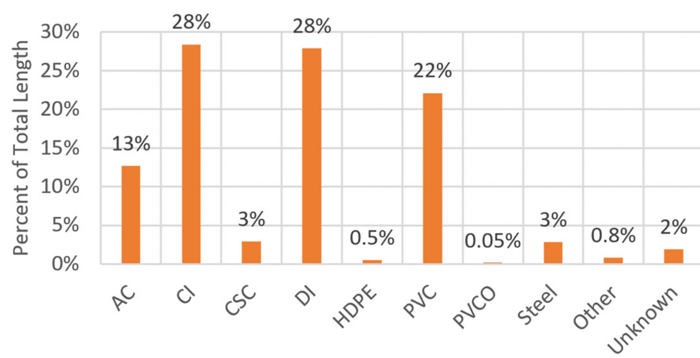

Figure 4. Percent of total length of pipe by material type.

PIPE AGE DISTRIBUTION

The detailed survey asked respondents to provide the distribution of installed pipe by age and by material type. Four age groups were provided; zero to 10-years, 10 to 20-years, 20 to 50-years, and over 50-years. The results showed that 28% of installed pipe are over 50-years old. Figure 5 shows the age distribution as a percentage of total length of all pipe materials. For example, cast iron pipe older than 50-years is 20% of all installed pipe. For ages between zero to ten years, ductile iron and PVC both have about 5% of the total installed length. That is, the most common pipe materials installed during the last 10-years is either ductile iron or PVC.

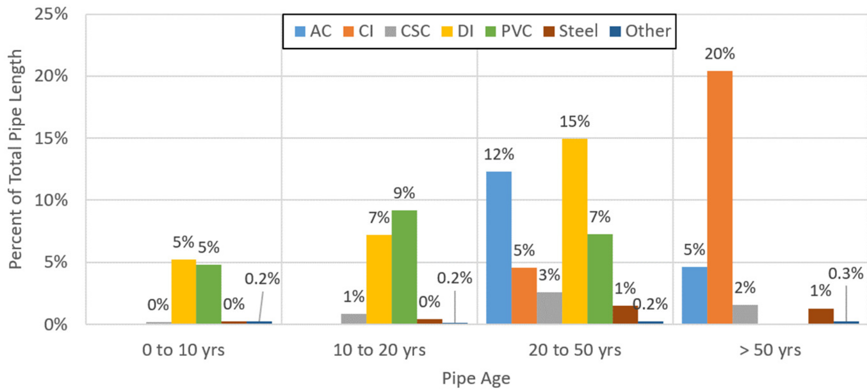

Figure 5. % of total pipe length by age groups and material type.

PIPE SIZE DISTRIBUTION

Pipe size distribution was examined in the detailed survey. Figure 6 illustrates the percentage of water main that fit into each size range. Figure 6 indicates that 67% of the installed pipe is 8-inches or less in diameter. The 2012 survey[2] found that 66% of the pipe was 8-inches or less in diameter showing good agreement. Earlier studies assumed 73% of water pipes were 10-inches or less in diameter[3].

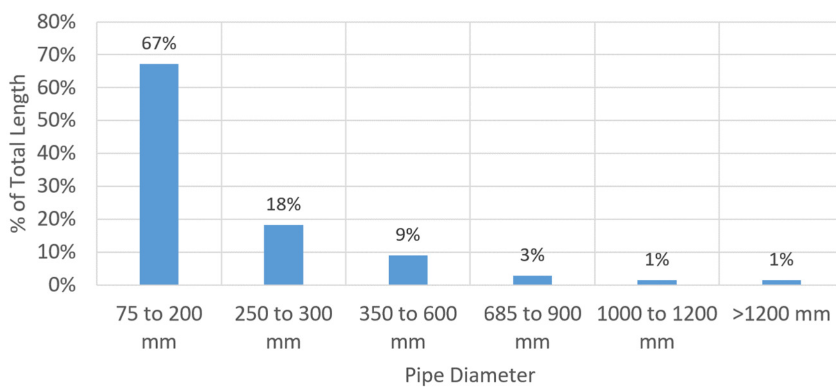

Figure 6. Percent of pipe length by diameter.

OPERATING PARAMETERS

The basic survey asked for the average and maximum water supply pressures. The mean values are 0.48 and 0.82-MPa. In the 2012 survey, the average pressure was 0.53-MPa which has good agreement with this survey result but also indicating a possible downward trend. It is noted that some utilities have reduced operating pressure to reduce leakage rates. The detailed survey asked for the average and maximum daily water demand. The reported values were divided by the population served and averaged. Utilities that were only transmission systems were excluded. The average water demand is 519-liters per day for each person. The maximum water demand is 950-liters per day for each person.

COMPUTING WATER MAIN BREAK RATES

Both the basic and detailed surveys asked respondents to consider a water main failure as one where leakage was detected, and repairs were made. However, they were requested to not report failures due to joint leakage, construction damage, or tapping of service lines because these failures are not indicative of pipe degradation and are often identified early in the first year of operation. The goal was to examine pipe longevity.

Utilities reported the number of failures over a recent 12-month period for each pipe material and the installed length of each pipe material. The failure rate was computed by dividing the total number of failures from all utilities for a particular pipe material by the total length of that pipe material. For example, the survey reported a total of 23,803 failures of water mains during a recent 12-month period for all pipe materials. The total installed water main length from the survey was 274,504-km (or 2745.04-hundreds of km). Thus, the overall failure rate is 23,803/2745.04 = 8.7 failures/(100-km)/year. Note that the 2012 survey had a rate of 6.8 failures/(100 km)/year or a 27% increase.

This simple method for computing failure rates was used because it discourages biases toward large or small utilities. It is noted that utilities experience widely different failure rates for the same pipe material. Indeed, this should not be surprising. Several significant variables affect the results including pipe age, soil types (corrosive or noncorrosive), different corrosion prevention techniques, different installation practices, and climate.

FAILURE RATES FOR EACH PIPE MATERIAL

The survey measured pipe failures over a recent 12-month period was broken down by material type. Table III lists the total length of pipe by material type, the number of failures (breaks) over a recent 12-month period, the break rate for each pipe material, the 2012 survey break rates, and the percent change in break rates. Figure 7 illustrates the failure rates as a function of material type for both the 2012 and 2018 surveys. Note that PVC was the pipe material with the lowest break rate in both surveys.

Table III. Summary of break data from the basic survey over a 12-months.

Material	Length (km)	Failures	2018 Break Rate	2012 Break rate	% change
AC	34,744	2,240	6.4	4.4	46%
CI	78,006	16,864	21.6	15.2	43%
CSC	7,950	152	1.9	3.4	-43%
DI	76,596	2,627	3.4	3.0	13%
PVC	60,679	878	1.4	1.6	-10%
Steel	7,668	362	4.7	8.4	-44%
Other	8,861	680	7.7	13.0	-41%
Total	274,504	23,803	8.7	6.8	27%

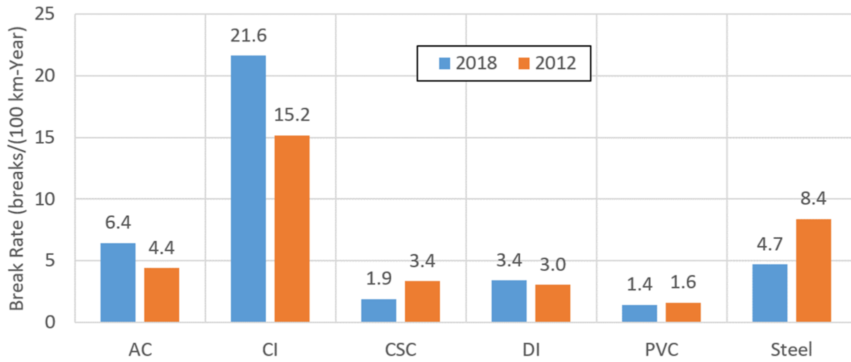

Figure 7. Break rates from the 2018 and 2012 surveys.

The accuracy of the break rate data is related to the amount of pipe included in the survey. Since over 90% of installed pipe consists of asbestos cement, cast iron, ductile iron, and PVC, the break rates for those material types will be most accurate. From 2012 to 2018, Fig. 6 shows a small decrease in break rates for PVC and a small increase for ductile iron. The overall consistency of those values demonstrates they are accurate. However, Table III shows that overall, break rates are increasing by 27%. That increase in break rates is primarily due to failures in asbestos cement and cast iron pipes with increases of break rates by over 40%. As Figure 5 shows, asbestos cement and cast iron pipe represent the largest percentage of oldest pipe currently installed and thus are nearing the end of their useful lives. Many studies show that water-main failure rates generally increase exponentially over time[4]. One could envision a rapid increase in break rates in the future. Certain utilities could experience the need to rapidly accelerate the rate at which they are replacing cast iron and asbestos cement water mains.

The amount of concrete and steel pipe in this survey are each about 3% of the total installed pipe length and thus the break rates for these materials will be less accurate. The decrease in break rate for concrete pipe was likely due to the fact that over twice as much concrete pipe is in this 2018 survey and should be more accurate. Steel pipe also saw a large increase in break rates. The break rate for steel pipes are largely attributed to smaller diameter galvanized steel pipes that are rapidly being replaced. Large diameter steel pipes used in transmission lines have a very low break rate.

EFFECT OF UTILITY SIZE ON BREAK RATES

The size of a utility can affect break rates. Three sizes of utilities are considered here based on the length of pipe; small with less than 320-km, intermediate with 320 to 1600-km, and large over 1600-km being a large utility. Figure 8 illustrates the overall break rate (for all pipe materials) and then broken down for the four most common pipe materials in these three utility sizes. The large utilities were able to consistently give lower break rates than intermediate and smaller utilities. This is likely due to better funding, better staffing for engineering design, to oversee installation, monitoring and information gathering, and repair of water mains. It is very significant that small utilities consistently have break rates at least double that of a large utility.

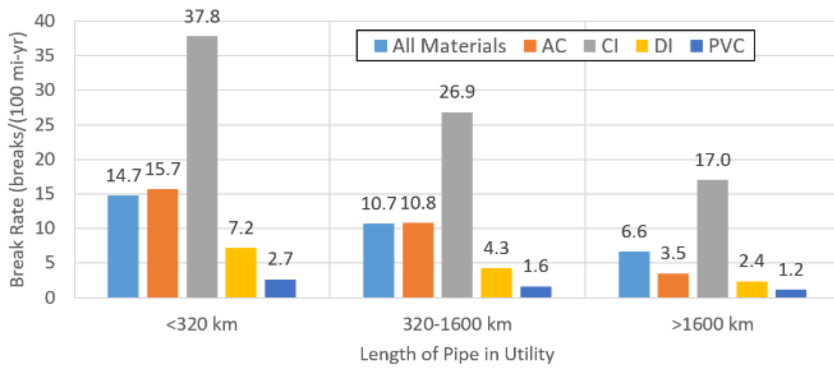

Figure 8. Break rates by utility size from the basic survey.

US VS CANADA BREAK RATES

Figure 9 compares US and Canadian break rate data from this study. Canada can have very corrosive soils and this is reflected in the high break rates of cast and ductile iron in Figure 9. Seargeant[5] reported that the highly corrosive soil in Edmonton necessitated a transition from cast iron to asbestos cement pipes in 1966 and then to PVC starting in 1977. The transition to PVC has produced a dramatic reduction in water main break rates for the city.

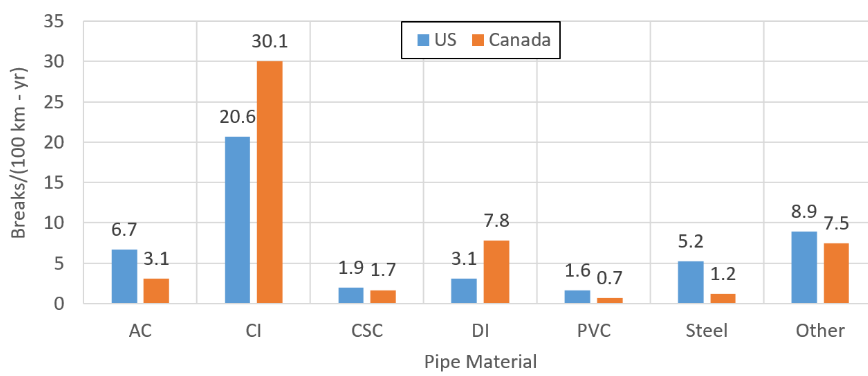

Figure 9. Break rates for US and Canada for selected materials.

MOST COMMON FAILURE MODE

The detailed survey requested participants to select the most common failure mode from the following: corrosion, bell split, circumferential crack, longitudinal crack, leakage at joints, fatigue, or other. Figure 10 illustrates that 56% of the respondents identified a circumferential crack as the most common followed by corrosion at 28%. These are the typical failure modes of cast iron and ductile iron pipes.

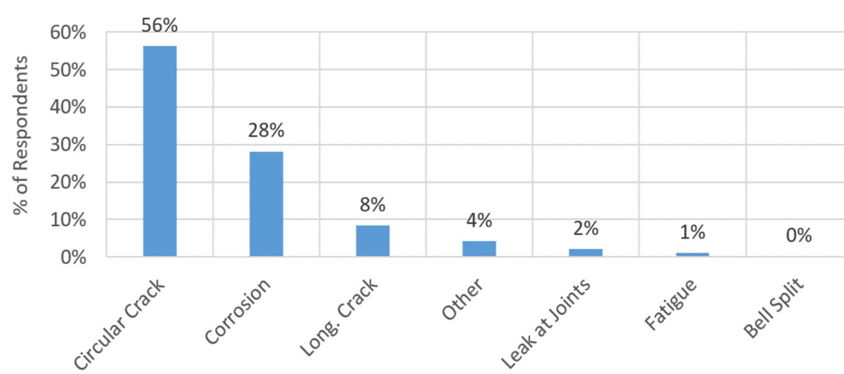

Figure 10. % of respondents selecting a most common failure.

EFFECT OF CORROSIVE SOILS

The USDA Natural Resources Conservation Service provides results of soil surveys across the US. One of the aspects of the soil surveys is a "risk of corrosion" analysis that pertains to potential soil-induced electrochemical or chemical action that corrodes or weakens uncoated steel. The soil is rated as either “low,” “moderate,” or “high” based on measurements of moisture, particle size, acidity, and electrical conductivity. This is not a precise analysis and additional factors may be neglected. Nevertheless, it is a reasonable estimate of soil corrosiveness in lieu of better data. The web site: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx allows the user to select an area of interest (AOI) and then produces a plot coloring low risk areas in green, moderate risk areas in yellow, and high risk areas in red. Soil risk can change over a distance of a few city blocks. This is illustrated in Figure 11 that shows a screen capture of a soil risk colors inside the boundaries of a town in California. This town has all three regions present; low (green), moderate (yellow), and high (red). Also, soil analysis data is not available in regions with a light gray color.

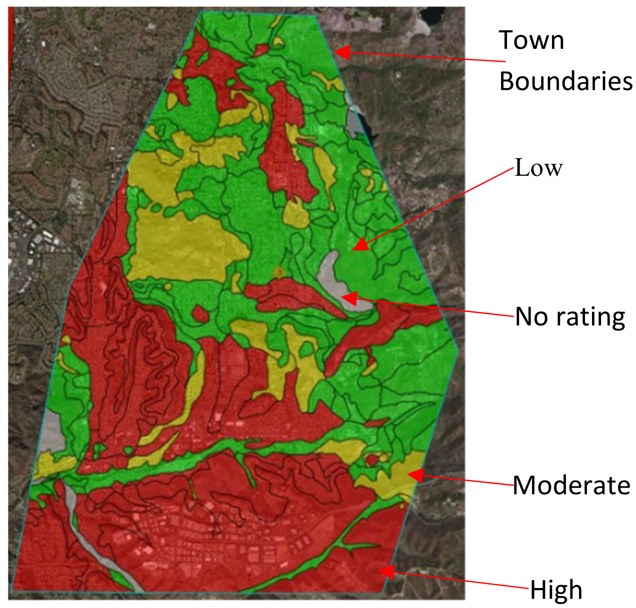

Figure 11. Soil corrosive risk plot.

It was desired to relate water main break rates to soil corrosivity. Since most cities have a combination of low, moderate, and high regions, a numerical ranking was desired that provided an overall level of soil corrosivity. To do that, pictures of each area served by the utilities in the basic survey were created. Next a program was developed that counted the number of reddish, greenish, and yellowish pixels in each photo. To provide a numerical ranking, pixels that were low risk were given a value of 1, moderate pixels were given the value 2, and high risk pixels were given the value 3. The pixel values were summed and then divided by the total number of red, yellow, and green pixels. The computed value is called a corrosion index. Cities with a corrosion index near 1 have low corrosion risk while those close the 3 have high corrosion risk. For the area in Figure 11, the computed corrosion risk was 2.1 or slightly above a moderate level of corrosion risk.

Corrosion index values were computed for 281 cities in the US. Some US cities had little or no data for the soil inside their boundaries preventing computation of a corrosion index. For analysis, the corrosion index values were broken down into seven ranges and the number of utilities in each range is plotted in Figure 12. The average corrosion index for all the US utilities in the basic survey was 2.4 or close to midway between moderate and high corrosion risk. That is, most of the utilities in the US have moderate to high soil corrosion risk which is consistent with the detailed survey report that 75% of the utilities have one or more areas with corrosive soils.

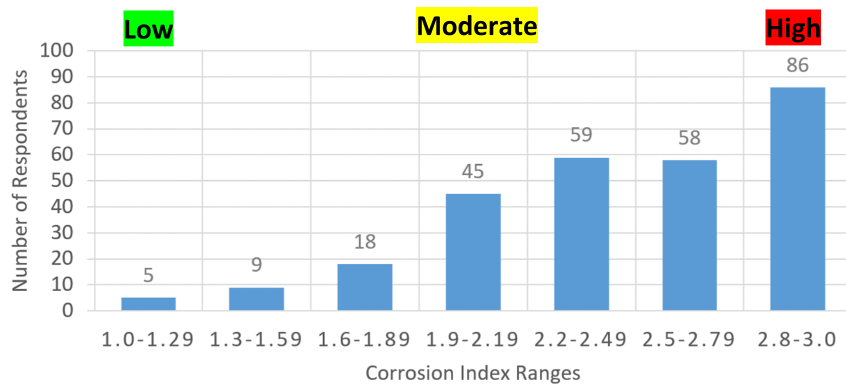

Figure 12. Number of utilities versus their corrosion index.

To get a realistic estimate of break rates, we need to add the number of breaks of a pipe type from several utilities and divide by the sum of the length of that pipe type to compute break rates. The corrosion index data was broken down into the same seven categories used in Figure 12. The break rates versus corrosion index data are plotted in Figure 13 for both cast iron and ductile iron pipe. The figure also contains regression equations and a correlation coefficient. Correlation coefficients close to 1.0 indicates an excellent correlation and zero indicate no correlation. Both of cast and ductile iron regression fits result in a reasonably good fit to the data.

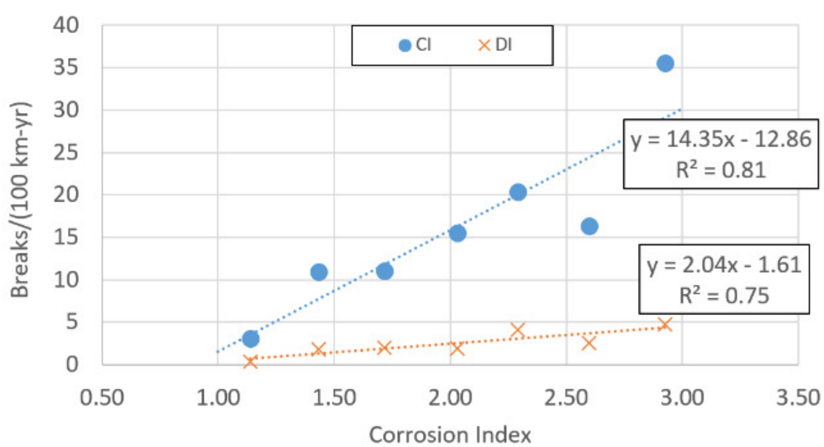

Figure 13. Cast and ductile iron pipe break rate versus corrosion index.

Using the equations in Figure 13 with x=1 for a low corrosion risk and x=3 for a high corrosion risk, one can show that a cast iron pipe in a high corrosion risk soil is expected to have over 20 times the break rate of a low corrosion risk soil. Similarly, ductile iron pipe in a high corrosion risk soil has over 10 times the break rates than one in a low corrosion risk soil.

CONSTRUCTION RELATED FAILURES

The detailed survey asked respondents to report failures related to construction activities. Figure 14 illustrates the percentage of total construction failures related to a particular pipe material. Ductile iron and PVC pipes have the majority of construction related failures at a nearly equal frequency. Figure 14 showed that Ductile iron and PVC are the two pipe materials that are also most commonly being installed.

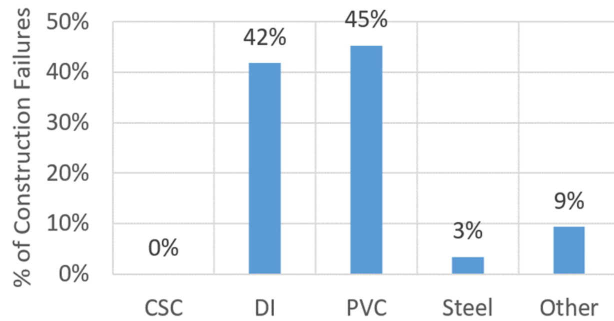

Figure 14. % of construction related failures.

PLANS FOR REPLACING WATER MAINS

The detailed survey respondents were asked questions about expected pipe life and pipe replacement. The typical age of failing water mains had an average response of 50-years which is well below what most manufacturers say should be expected. The average expected life of a newly installed pipe is 84-years.

The detailed survey asked utilities if they had a regular pipe replacement program and only 58% of the respondents stated they did and of those that did, the average amount replaced each year was 0.8% of their total installed length. A 0.8% replacement rate corresponds to a 125-year replacement schedule. Clearly, pipe replacement rates are inadequate.

Respondents were asked for the percentage of the water mains that are beyond their useful life but lacked funds to replace them. The average response was 16% of water mains are beyond their useful life. In the 2012 survey the same question was asked and the response was 8.4%. This would indicate that the backlog of needed pipe replacement is growing.

CONCLUSIONS

This Comprehensive Water Main Break Study for 2018 surveyed a statistically significant amount of utilities that have collected data on their underground infrastructure. This survey was focused on material usage in water mains across the USA and Canada. This effort was successful in getting 281 participants to respond to a basic survey with water main break data and 98 utilities responded to a detailed survey. The central focus of this survey was to obtain average values for water main break rates across the US and Canada. There are numerous results to this survey but the most significant is that in both the 2012 and 2018 survey, PVC has the lowest break rate of all the pipe materials considered. Plastic pipe that does not corrode is shown here to be an excellent choice for pipe installation. Page limits prevents reporting all the results here. The final report for this study is available from: http://digitalcommons.usu.edu/mae_facpub/174/.

ACKNOWLEDGMENTS

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