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White Paper: Corrosion and Cracks in Water Pipes: Can We See Them Sooner?

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Corrosion and Cracks in Water Pipe Mains: Can we see them sooner?

Cast Iron pipe water mains:

Used for transporting water under relatively high pressure, cast iron has been used in the manufacture of water main pipes for over 500 years. Cast iron pipes were first used in Philadelphia about 200 years ago. Buried under city streets, they are lifestreams for cities and towns. No one ever really thinks about these mains, until one breaks. According to the Environmental Protection Agency's Aging Water Infrastructure Research Program, there are an estimated 240,000 water main breaks each year and it threatens to get worse as the infrastructure ages. Most of the main breaks are due to corrosion of the cast iron, a process related to age in a hostile soil environment. Depending on the size of the water main (some may be over six feet diameter), as these mains break, up to hundreds of millions of gallons of drinking water are wasted that severely damage property and cause possible loss of life. In 2009 drivers have been stranded, mudslides have occurred, libraries flooded and the NYC subway service was disrupted due to water main breaks. (Cooper, Michael. "In Aging Water Systems, Bigger Threats are Seen." New York Times. April 19, 2009, p. 14). Large diameter pipeline assets often have a low failure rate, but can have catastrophic results when they do fail. It can lead to flooding, damage to property, disruption to traffic flow on highways and direct and indirect costs to the municipality. Throughout the Northeast and Midwest, aging water transmission mains are showing signs of corrosion.

The public's health and safety depends upon a pure, adequate and reliable supply of water. Water was once plentiful and cheap, but that is no longer true. Recycled water, energy efficient appliances, low water landscaping, artificial turf, and other conservation methods, while necessary where the supply of source water is limited, should not be relied on to compensate for a leaking, failing, distribution system.

American Water Works Association estimated in 2001 that it will cost U.S. water utilities $325 billion over the next two decades to upgrade water distribution systems. It has termed this "the dawn of the replacement era." There have been physical probabilistic failure models developed in relation to soil types that may lead to uncertainty in external surface corrosion rates. However, the models lack the details of actual degradation. Variations in water chemistry in contact with the pipe's inner surface lead to uncertain leaching rate in cement based pipes. It is not only the loss of water we should be concerned with, but the possibility of water contamination in a damaged water system with the potential to cause widespread illness and a further drain on the economy. The cost effective question becomes: How do we determine which pipes should be replaced before they break?

Justification for Government Attention:

Water is one of the basic needs of man. According to the U.S. Geological Survey, the estimated use of water in the United States in 2000 was about 408 billion gallons per day for all uses. Thermoelectric power and irrigation were the largest users of fresh water. More than 43 billion gallons per day was drawn by public water systems to serve drinking water to 85% of the population in the U.S. A public water system includes the watershed from which water drains to a reservoir where water is impounded behind a dam or in an aquifer; transmission mains to deliver the water from the reservoir to the treatment plant for the removal of impurities, and after treatment, pumping to a distribution water storage tank or basin through pipes, and then again through pipes from distribution storage to consumers. Many of these pipes are aging and difficult to take out of service, especially large transmission mains. Bearing this costly burden is disproportionately high. In 2005, the U.S. Environmental Protection Agency Drinking Water Infrastructure Needs Survey and Assessment estimated that $277 billion would be the cost to replace the aging infrastructure (Young, John. "The Infrastructure Crisis," Journal AWWA April, 2007, p. 56). It is common to have pinhole leaks, hairline cracks and leaking gaskets before there is a large blowout of a pipe wall. We know corrosion plays a big part in this scenario, but so do soil pipe interactions, poor pipe casting and human error. The risk factors include: cast iron pipe material, lead sulfa based joint compound used in the 1930's to 1950's, heavy traffic loads, pressure transients, and impacts from construction in the area and installation practices. (Kunkel, George, Laven, Kevin and Mergelas, Brain. "Does Your City Have High Risk Pipes?" AWWA, April 2008 p. 70.)

There is relatively little physical data collected on pipes. Most of the data that is recorded includes the age, material, and characteristics of the pipe along with the surrounding soil. Some municipal water systems collect water main break data such as the nature and the frequency of breaks on a segment of pipe in the distribution system. One of the aspects of a water main break is to determine the nature of the failure. Some of the most common types of failure are leaking joints, leaking service connection, leaking valve, longitudinal breaks, corrosion pit hole and others with the majority being leaking joints and valves. Water main breaks may lead to contamination of the distribution system through back siphonage of water from contaminated sources such as hoses connected to outdoor fixtures used to fill containers or dilute toxic chemicals in a barrel. (Wood, Andrew & Lance, Barbara J. "Assessment of Water Main Break Data for Asset Management," Journal AWWA, July 2006, p. 76). Locating and evaluating potentially weakened pipe for a scheduled repair or removal before an unplanned break occurs would save the loss of water in which significant public investment has been made in treatment and transmission together with prevention of collateral damage to nearby infrastructure such as sewer lines, roads and buildings.

According to Davis and Marlow (Davis, Paul and David Marlow, "Asset Management: Quantifying Economic Lifetime of Large Diameter Pipelines." Journal AWWA, July 2008 p. 117) in writing about different nondestructive inspection techniques wrote: "…This may mean that depending on the particular technique chosen, a different number of discrete inspections are needed to adequately define the corrosion rate probability distribution which in turn will change the inspection cost. Further work is needed to determine the relationship between the required number of inspections and the corrosion rate distribution accuracy for different inspection tools."

The chemistry of water and its characteristics may affect corrosion in pipes. pH, alkalinity, salts and chemicals that are dissolved in the water is principally controlled by monitoring and adjusting these concentrations. This is important when dealing with metal pipes. What about leakage? A leaking pipe can be an indication of a weakened pipe in the distribution system. Not all leaks are visible; sometimes they drain into sanitary and storm sewers, into porous underground formation, into absorbent soils, into creeks, etc. Leak detection surveyors may use a listening device to find leaks on pipes, valves and other fittings since leaks produce a unique sound. However, it takes an experienced person with specialized equipment and time to be successful. The state of Washington's Dept. of Health Water Use Efficiency Rule requires most water systems in the state to meet a leakage standard of 10 percent or less. Washington's DOH recommends that a leakage survey be done every year or every other year to avoid problems. ("Reduce Leaks: Using Water Audits and Leak Detection Surveys", Washington State Department of Health, February 2008, DOH Pub. #331-388)

Therefore, more water main breaks can be avoided by early detection of corrosion, cracks, and structural defects. But what other methods may be employed to identify these problems? The use of imaging such as x-rays, ultrasounds and infrared, are technologies that have been used for gathering more information. Two of the more common methods in field assessment have employed the use of ultrasonics and magnetic particle techniques. (MT).

These are usually done by exposing the pipe, commercial sandblasting of the pipe, and a visual inspection with an MT done on every corroded area determined from field inspection. Ultrasonic testing surveys the thickness of the pipe and therefore indicates the general thinning and localized pitting that is present. It measures the time needed for a burst of sound to travel from the source to a target area. It has been used fairly extensively in sewer pipelines but it can not be used in both air and water simultaneously. (Eiswirth, M. and Burn, L.S. “New Methods for Defect Diagnosis of Water Pipelines.” International Conference on Water Pipeline Systems, 28-30 March, York, UK). A drawback to ultrasonics is that it is very operator dependent.

An electronic pipeline inspection gauge (pig) shows promise, a device that is used in oil and gas main pipes. There are four main uses for a pig: to transport different liquids in pipelines, internal cleaning of pipelines, recording size and position of pipelines and the inspection of the condition of pipeline walls. The last use sometimes incorporates smart pigs, they are basically a computer that collects data during the trip through the pipe. They can also use technologies such as Magnetic Flux Leakage (MFL) and ultrasonics to detect surface pitting, corrosion, cracks and weld defects in steel/ferrous pipes. (“Dumb” pigs are used by water utilities to clear tubercles, accretions on the inside of cast iron water mains that may occlude 50% or more of the inside diameter of smaller distribution main.)

Pigs may not always be a reliable source of information. Traveling long distances may damage the probes invalidating the nature of and the specific spot of the defect. Furthermore, the current state of the technology limits the pigs’ communication with the outside world. To be totally effective, pigging should be done every year to evaluate the rate of deterioration of a particular defect so proactive plans can be made to repair the pipe before any leakage.

Another method being used is infra-red thermography which utilizes high resolution temperature methods to detect leaks and corrosion. The theory is that water leaking from an underground pipe changes the thermal characteristics of the surrounding environment. The scanners are used to detect thermal anomalies above the pipes.

Radiographic inspection provides more information on the state of a pipe than any other method in common practice. However, it uses dangerous ionizing radiation, it requires access to both sides of the component being inspected and it is expensive. The newer computed radiography uses photostimulable plates. These plates are reusable, more efficient at collecting data than film and the latent image is digitized. There are other methods for grabbing radiographic images such as: lens-couple, charge couple devices; direct imaging flat panel devices; linear arrays and image intensifiers. (Howard, Boyd D., Gibbs, Kenneth and Elder, James B. "Corrosion Detection Devices," Westinghouse Savannah River Company, Army Corrosion Summit-2004. Westinghouse Savannah River Company, Aiken, SC).

In 1983 Dr. James C. Tilton of NASA/GSFC began to develop hierarchical technologies in earth science and remote sensing. His vision was to see image segmentation and analyzing the data beyond the typical 'per pixel' approach when a pixel did not provide enough information as to where it fit in the bigger picture. A result of this on-going research has been Recursive Hierarchical Segmentation (RHSEG). RHSEG is a computer program and an algorithm that implements the algorithm that performs RHSEG of data. This newest version eliminates artifacts. This allows improved extraction of patterns from complex data sets with speed and accuracy. It allows the user to group non-spatially adjacent regions. Images can be two dimensional or three dimensional single band, multispectral or hyperspectral. It can be used for a wide range of applications in image data mining. It can be used for aircraft or satellite remote sensing, analyzing ground penetrating radar, x-ray image analysis, image data mining, thermal image analysis and sonar and radar data analysis among others.
RHSEG partitions two and three dimension image or image-like data into regions or clusters at various levels of detail. Using RHSEG, analysis can hierarchically relate regions of data at coarser levels of detail to regions of data at finer levels. After being processed by RHSEG software, data are grouped and can be analyzed in terms of hierarchically related regions, rather than as individual data points, enabling a more consistent and accurate analysis.
If this process can be applied to methods already being used to detect leaks, cracks or corrosion then the information gathered can be improved since RHSEG can 'see' information the human eye misses in a digital image expediting the analysis of data

Therefore, the question becomes, can new technology improve the images we are now seeing from the different modalities to detect cracks and corrosion? As stated in by Ratiliffe, Allison, Fox, Steven R. and Eric Frechette in Opflow July 2009, AWWA: p. 18. "Buried pipeline often operate in a state of anonymity with respect to corrosion until deterioration is severe enough to cause failure."