The political landscape for utility managers is changing as sink holes, plaque cities and boiling orders to customers become commonplace. Elected officials are also feeling the pinch with limited funds, increasing operational costs and the need to understand and explain corrosion issues to their rate base. It is in this new public water climate that better pipe selection material decision making is an absolute.

Beyond pipe age, corrosion — both internal and external — is creating premature failure of water and wastewater systems. Utilities are faced with reviewing new methodologies and pipe materials to select the best fit and the right cost solution while reducing the future risks of poor water quality, contamination, expensive maintenance programs and premature pipe failure.

The Basics in Controlling Corrosion

In general, the three most common techniques for controlling corrosion are: adding chemicals to the water to make it less corrosive; creating protective barriers between the water, pipe and soil; and switching to pipe materials that are non-corrosive. For existing pipes, most utilities are choosing to do all three. First, treating the water as an ongoing cost of operating the system. Second, developing costly corrosion control programs and applying various rehab and repair techniques to extend the pipe life. Finally, when the pipe requires replacing, switching to a non-metallic, non-corrosive pipe. While there are many options to choose from, the issue of durability, strength, longevity, cost and future corrosion concerns are the final decision points. Doing things the same old way and expecting different results does not meet the standards of an effective managed utility in the 21st century.

Corrosion Causes Pressure Loss, Contamination

The hydraulic capacity of water distribution systems can be compromised due to damage to the pipe surface. Any build-up inside the mains can greatly reduce the hydraulic performance of the system. Corrosion and tuberculation on the interior of the pipes can seriously restrict the flow of the water and obstruct water lines, creating excessive pressure losses and further weakening aging pipes, which, in turn, increases residence times and reinforces corrosion.

The main reason for the reduction in carrying capacity is that the pipes' inner surface becomes rough, leading to increased friction (head loss) and resistance to flow. Internal corrosion is the deterioration of the inside wall of a pipe or fitting caused by reactions with the water. This deterioration can erode the lining or surface coating of a pipe that can result in chemical dissolution that leaches metal from the pipe wall. Severe scaling may also significantly reduce the diameter of the water pipe, resulting in even larger losses of carrying capacity (head loss is inversely proportional to the pipe diameter). The loss of water pressure reduces the ability of a utility to deliver water and causes interruptions in times of pipe failure. Dangerously low or negative pressures can also develop during high demand periods at various locations in the system.

The existence of negative pressure in the water distribution system can result in pipe collapse, infiltration of contaminated water via cross-connections and the inability to meet imposed demands. The formation of scales on the inner pipe walls during periods of low flow may also lead to the release or re-suspension of associated deposits when water velocity is increased or flow direction is reversed, which will affect the quality of the water. Debris
within the distribution system may also have an adverse effect on the various fittings, rendering them inoperable or having fire hydrants become heavily encrusted, reducing fire suppression capabilities.

**Pipe Material Selection**

Pipe is made from many different materials depending upon the properties of the media that is being transported. For example, pressure is used to transport potable water to the end user. A pipe that has high pressure rating (typically greater than 150 psi) must be used. It would also be desirable for the pipe to have a smooth interior to promote good flow. While many different types of pipe have these qualities, the most common for use in potable water distribution are PVC pipe and ductile iron pipe.

For high pressure, larger diameter applications, precast concrete pressure pipe (PCPP) and spiral welded steel pipe are practical. These are just typical materials that are used when designing a project; a civil engineer will carefully review all of the practical options and make a selection that is then incorporated into the design. Civil engineers are also able to recommend the use of PVC for larger diameter replacement options as part of a capital replacement program strategy to both maintain durability and reduce costs.

**Corrosive Soils and Clay Soil Challenges**

Corrosion is a process by which metals break down due to chemical or electrochemical reactions with the environment. Corrosion can cause "pits" to develop into small holes in cast iron or ductile iron pipes. The highest corrosion rates occur on water mains with copper service connections located in soils such as clay. The added moisture caused by a water main leak can reduce the soil resistance and result in increased rates of external corrosion. Leaks can also erode the ground or "bedding" surrounding a water main, ultimately causing the piping to collapse. Additionally, cast iron water mains with sulphur-mortar joints are more susceptible to corrosion and pitting around the joints.

Shifting clay soil presents another challenge for underground pipes. The heat wave in the summer of 2011 created thousands of water main breaks and pressure problems as the clay soils of Texas cracked and shifted the rigid metallic pipes vulnerable from corrosion and failed due to heat and pressure.

However, successful stories do arise from these types of adverse working environments that are worth mentioning. The City of Fort Wayne, Ind., also has shifting clay soils where cast iron mains would start to have corrosion-related leaks. In dry summers, the clay soil would fracture 3 to 4 ft deep and twist the old cast iron pipes installed in the 1950s and 1960s. With a limited budget and the goal to replace 1 percent each year (and the expectation that pipe will last over 100 years), a replacement strategy using non-corrosive thermoplastic pipe material for lower maintenance and increased longevity was used. The performance of restrained-joint PVC pipe in this HDD application replacement combination proved to be a better choice for the project than an open-trench installation of HDPE pipe. Backfill material usually contains a high percentage of fly ash, and unlike concrete, it is very porous and can become corrosive.

**Ductile Iron Wall Thickness: No Match for Corrosion**

Another common cause of water main breaks is related to the thickness of the pipe wall. Changes in manufacturing processes and materials led to the thinning of pipe walls between the 1800s and 1960s. As a result, water mains constructed during the late 19th century have thicker walls than water mains constructed during the 1950s and 1960s.

Small water mains with thinner pipe walls are more likely to break, making them more vulnerable to the effects of corrosion. As a result, newer and thinner pipes, such as a 50-year-old water main, may deliver a shorter service life than an older, thicker-walled water main. The walls of the ductile iron pipe have also been gradually made thinner over time (a 76 percent reduction in size at 1.58 in. in 1908 to 0.38 in. in 1991). In soils that are considered corrosive to ductile or cast iron, it has long since been proven that the use of sacrificial metal (i.e., additional wall thickness) for corrosion protection is neither reliable nor cost-effective.

**Proper Inspections Prevent Premature Failures**

A number of case studies have demonstrated the negative effect of inadequate inspection or quality control at some point in the process from manufacture to installation. The pipe failures have included asbestos cement pipe (ACP), welded steel pipe (WSP), prestressed concrete cylinder pipe (PCCP), ductile iron pipe (DIP), PVC and HDPE, conventional reinforced concrete pipe (RCP) and especially vitrified clay pipe (VCP). Some of the failures occurred after 10 or 15 years of service, while others after as little as one or two years of service, and some occurred during installation. No pipe material is "bullet proof." No pipe material is exempt from failure in the absence of proper design followed by adequate inspection. A poorly informed inspector, or one who has not been properly trained in the manufacture, inspection, handling, installation and testing of the type of pipe he or she is hired to inspect, is often worse than no inspection at all.

**Renewal Planning**

The U.S. Environmental Protection Agency’s (EPA) newly published study in 2011 on "Decision Support for Renewal of Wastewater Collection and Water Distribution Systems" helps provide...
the overall renewal framework. Once a pipe segment is considered to need remediation, many parameters must be considered to determine what technologies may or may not be applicable. These parameters include: 1) hydraulic capacity; 2) existing alignment; 3) pipe length; 4) diameter; 5) depth; 6) hazardous conditions; and 7) host pipe access and location.

When hydraulic capacity is limited, any technology that would reduce the capacity even more is not usually considered and open cut or pipe bursting would be considered as viable options. Another parameter lending itself to open cut replacement is misalignments. Sags and multiple bends can limit the cost-effectiveness of pipe bursting and sliplining, which would require more pits, as well as CIPP, where bends and sags can cause problems with robotic lateral reinstatements.

The length of the host pipe and diameter can be limiting factors for some technologies depending on the specific capabilities of a technology. Also, longer lengths of pipes typically reduce unit costs by reducing the mobilization cost for a particular technology.

**Open Procurement and Financial Analysis: Prudent Public Policy**

For water mains, the decision to replace or rehabilitate a pipe is typically determined by two parameters: 1) the number of breaks in the main and 2) the number of leaks along the main. For water mains determined to be in need of remediation, typically without further analysis, the main would be replaced with a ductile iron pipe using open cut construction. Due to various inputs, the reselection of just installing another metallic pipe might be warranted. But it is an important public and financial policy to ensure that open procurement practices are in place and the financial analysis of an open cut non-corrosive pipe material is also considered to “value engineering” and reduce the overall capital program costs while also reducing long-term maintenance costs.

**Trenchless PVC and HDD**

Engineers and contractors are continually challenged with evaluating alternative pipe material and construction options for best meeting their project needs. Traditional open-cut construction methods have proven design and installation specifications. However, the increase in utilization of trenchless construction methods has facilitated the development of pipe materials suited for such installation methods. Today, technologies such as horizontal directional drilling (HDD) have increased significantly as an alternative installation method in the municipal sector. Installation of potable water, force mains, reclaimed water and gravity projects employing directional drilling have grown as demand for installations in difficult areas, like under rivers, major highways or highly urbanized and congested utility corridors, has increased. The nature of the HDD process necessitates the use of continuously joined pipe products capable of being pulled in, as opposed to pushed in by segmental installations. Trenchless PVC pipe is one such material for installation of water and wastewater, pressure and non-pressure infrastructure using HDD.

**Corrosive California Mixed-use Pipe Segment Replacement**

Many times an entire pipeline cannot be replaced, and may not even need to be replaced. One option is mixed use segment replacement where existing iron fittings are used in conjunction with PVC pipe segments replacing the failed iron and ductile iron pipes. This process has existed for years. As an example, in the corrosive soils of the California coast, the U.S. Naval Air Station Point Mugu in Ventura County, Calif., used PVC in an open-trench project and replaced pipes by jumping around and using PVC with ductile iron fittings to handle the many changes in direction. However, one result was the need for cathodic protection and setting up individual cathodic for over 300 test stations. The ductile iron fittings were used at valves and for T-shaped directional changes, but in an effort to save time and money, CertainTeed C900 RJ Sweeps were used in place of ductile iron fittings at all angle changes. The PVC sweeps did not require cathodic protection. Corrosion-resistant restrained-joint PVC pipes and sweeps in corrosive California soils helped save valuable time.

Corrosion as an epidemic introduces a great number of political challenges and renewal remedies. It is through these difficult lessons that we can gain some clarity and make replacement decisions that begin to eliminate corrosion for future generations.

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