Abstract
This paper will discuss the current design practices for the primary water transmission products in the US: steel pipe, concrete pressure pipe and ductile iron pipe. It details a more efficient approach to the design of pipe materials and the preparation of equal alternate specifications. Today’s steel, concrete and ductile iron pipe industries utilize the Pressure Class Design approach. The differences in the design of the three products are demonstrated using consistent performance criteria as established in the specifications. American Water Works Association (AWWA) design and installation manuals M9, M11, and M41 cover concrete pressure pipe, steel pipe, and ductile iron pipe respectively. The products are also covered by AWWA manufacturing and quality assurance standards. Utilizing these standards in a project’s design specifications capitalizes on the decades of work and knowledge already invested by industry peers. This paper will compare the Pressure Class Design approach procedures and provide useful tools for engineers and owners in the design and specification of water and wastewater transmission lines.

Introduction
Many hours are typically spent designing and preparing specifications for large water or wastewater transmission lines. Owners can expect the longest lasting pipeline design at the best possible price. Often, engineers can become overwhelmed in an attempt to develop specifications for alternative products that accomplish these objectives. Through the use of performance-based specifications via the Pressure Class Design approach, many of the problems associated with specifying equal alternative materials can be avoided. More importantly, the owner will receive a pipeline that provides them with the performance criteria they need.

Pressure Class Design, based on the pipe’s ability to hold internal pressures, is not a new concept. Concrete pressure pipe has always utilized Pressure Class Design. In 1991, the ductile iron industry standardized on Pressure Class designations in lieu of Thickness Class designations. While steel pipe has also utilized Pressure Class Design concepts through the years, only recently has it become the trend in the industry. Standardizing the performance standards for all transmission main pipe provides consistent designs, equal performance and the best long-term value for the owner.

Under Pressure Class Design, a manufacturer needs only a few criteria to design the most structurally efficient pipeline to suit project performance requirements. These include internal pressure (working, transients and test), external loads (live and dead loads), collapse pressures (from hydraulic or atmospheric pressures), special physical loading (pipe on supports, if above ground), physical requirements (ability to handle or ship) and appropriate corrosion protection. Equal alternate specifications that reflect the standard performance expectations can be prepared. Combining this information with the contract
drawings, manufacturers provide all necessary pipe design calculations and line layout drawings.

**Pipe Materials**

Steel pipe, concrete pressure pipe and ductile iron pipe materials are different yet they are alike. The key similarity is that they all depend on ferrous components (steel, high tensile steel wire, steel bar and or iron) to withstand internal pressures. The same ferrous components plus cement-mortar linings and coatings if applicable resist external pressures. As such they are all subject to corrosion and deterioration if corrosion protection is not provided. Prestressed concrete cylinder pipe (PCCP) is a rigid pipe material while ductile iron (DIP), bar-wrapped concrete cylinder pipe (BWCCP) and steel pipe are flexible pipe materials (In diameters less than 36 inch, these pipes may act as a “semi-rigid” pipes but flexible pipe design theory is used for external load design. Hence this paper will use the term “flexible pipe” to reference all non-rigid pipe materials). Rigid pipe designs use the stiffness of the pipe wall to support the external loads and internal pressures without cracking. Flexible pipe designs depend on the soil and pipe wall stiffness to jointly support the external and internal loads. Appropriate bedding and backfill materials are important for both flexible and semi-rigid pipe. Improperly installed flexible pipe may deflect excessively while improperly installed rigid pipe may settle differentially, crack and or break. Proper bedding allows for efficient transfer of the loads acting on the pipe wall into the pipe bedding. Proper bedding support (bedding angle) is a key component of the pipe wall design for pipe and especially rigid pipe.

**Current Design Practices**

As a consultant or owner, the prospect of designing and funding a water transmission project is challenging. Permitting, right-of-way acquisition, funding, environmental or social issues and other challenges associated with larger, high profile projects appear to be ever increasing. The time required for these challenges too often limits the time available to evaluate and fairly specify competitive pipe materials. This can be very costly since these materials typically comprise 30-50% or more of the project cost. Evaluating alternate materials on a technical basis in order to write a fair specification can be overwhelming. The Pressure Class Design approach simplifies the process, providing equivalent performance requirements, thereby assuring the owner gets the best value utilizing proven AWWA design and quality standards.

**Pipe Design and Quality Assurance Overview**

PCCP, BWCCP, steel pipe and DIP are designed utilizing AWWA design guidelines M9, M11, and M41 in conjunction with standards C301, C304, C303, C200 and C150 respectively. These AWWA design guidelines and standards cover all aspects of design and construction. Other AWWA standards provide quality and testing guides to assure the owner of reliable products and installations. These documents are the “Bible” for each pipe material and serve as “industry standards.” These standards are developed by a consortium of individuals from user agencies, consulting engineers and manufactures that represent the best engineering evaluations and practices. These standards provide conservative designs and provide assurance of high quality pipe materials. Designers should become familiar with and utilize these documents extensively in their
specifications. Referencing AWWA standards in a project’s specifications also saves the engineer time because they do not have to repeat requirements already called out in the standard.

**Pressure Class Design**

**Internal Pressure**

The differences between the operating energy grade line and the low point in the pipeline normally determine working pressure ($P_w$). Surge or transient pressure ($P_t$) adds a maximum surge energy grade line. Design pressure ($P$) then becomes $P = P_w + P_t$. Wall thickness for internal pressure is a straightforward pressure class design check for flexible pipe. Steel pipe and DIP utilize the Barlow Hoop Tension formula for wall thickness ($t$) determination as detailed in Equation 1. Equation 2 details the calculation for steel thickness ($t$) for working pressure only. Equation 3 details the required steel only wall thickness ($t$) when checking for $P = P_w + P_t$ or surge pressure.

\[
t = \frac{(PD)}{(2s)} \quad \text{Equation 1}
\]

\[
t = \frac{(P_wD)}{(2(0.5*Yield))} \quad \text{Equation 2}
\]

Design Stress ($s$) is limited to 50% of the yield strength of steel

\[
t = \frac{((P_w + P_t)D)}{(2(0.75*Yield))} \quad \text{Equation 3}
\]

Design Stress ($s$) is limited to 75% of the yield strength of steel

Where:

- $P = $ Pressure (psi)
- $D = $ Outside Diameter (in)
- $s = $ Design stress (psi)
- $t = $ Wall thickness (in/in)
- $P_w = $ Working pressure condition
- $(P_w + P_t) = $ Transient pressure condition or Surge pressure

BWCPP also utilizes the Barlow Hoop Tension Formula but calculates the total cross section ($A_s$) required from the combination of the thickness of the steel cylinder and the mild steel bar wrap. The required steel cross-section ($A_s$) is computed per lineal foot or 12 inches of pipe in lieu of per inch of pipe as in Equation 1 for steel or DIP. The rewritten Equation 1 with the conversion from inch to feet then becomes:

\[
A_s = 6(PD)/s \quad \text{Equation 4}
\]

Equation 5 determines $A_s$ required for Working Pressure ($P_w$) and Equation 6 determines the $A_s$ required for Surge Pressure of $(P_w + P_t)$. The greatest $A_s$ controls design for internal pressure similar to Equations 2 and 3.

\[
A_s = 6 \ (P_wD)/s \quad \text{Equation 5}
\]

Design Stress ($s$) is limited to 50% of the yield strength of steel but can not exceed 18,000 psi per M9 to protect cement-mortar coating from cracking. Hence BWCCP is limited to steel with a 36,000 maximum yield.
\[ A_s = \frac{6(P_w + P_t)D}{s} \] 

Equation 6

Design Stress \( s \) is limited to 75% of the yield strength of steel but can not exceed 27,000 psi per M9 to protect cement-mortar coating from cracking.

Where:
- \( D \) = Outside Diameter (in)
- \( s \) = Design stress (psi)
- \( A_s \) = total cross-sectional steel area (in\(^2\)/ft)
- \( P_w \) = Working pressure condition
- \( (P_w + P_t) \) = Transient pressure condition or Surge Pressure

PCCP and BWCCP fittings are typically designed for internal pressure using Equations 1, 2 and 3 and utilize steel pipe in the production of the fittings due to manufacturing limitations.

Unlike flexible pipe designs, PCCP design for internal pressures and external loads is quite complex. Pipe wall designs are provided by the manufacturer. Consultants or owners can not check the concrete pipe wall designs without proprietary software from the concrete industry. The Pressure Class Design approach offers a practical way to design PCCP for transmission line projects.

Table 1 details minimum pressure classes, surge pressures, field test pressures by product and suggested minimum pressures (performance standards) for Pressure Class Design. If higher pressures are expected, all pressures should be increased accordingly. Economical intervals of 25 psi are appropriate for \( P_w, P_t \) or \( P_n \) (field test pressure).

**Table 1**: Available & Recommended Design Pressures for Pressure Class Pipe

<table>
<thead>
<tr>
<th>Performance Standard</th>
<th>C301 Concrete Pressure Pipe</th>
<th>C303 Bar-wrap Cylinder Pipe</th>
<th>C151 Ductile Iron Pipe</th>
<th>C200 Steel Pipe</th>
<th>Minimum Design Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Pressure (( P_w ))</td>
<td>25 psi or less</td>
<td>100 psi</td>
<td>150 psi</td>
<td>150 psi</td>
<td>150 psi</td>
</tr>
<tr>
<td>Surge Pressure (( P_s ))</td>
<td>Greater of 40% of ( P_w ) or 40 psi</td>
<td>50% of ( P_w )</td>
<td>100 psi</td>
<td>50% of ( P_w )</td>
<td>50% of ( P_w )</td>
</tr>
<tr>
<td>Field Test Pressure (( P_n ))</td>
<td>120% of ( P_w )</td>
<td>120% of ( P_w )</td>
<td>125% of ( P_w )</td>
<td>125% of ( P_w )</td>
<td>125% of ( P_w )</td>
</tr>
</tbody>
</table>

**Earth Loads**

Flexible pipe and rigid pipe resist earth and live loads differently. In either case, begin with determining whether the pipe will be installed in a trench or embankment condition (positive or negative embankment condition). The Marston theory demonstrates that it is advantageous to install a pipe in a trench that is no wider than twice the diameter of the pipe but always wide enough to permit proper placement of haunch and side fill materials. The prism of backfill above the pipe tends to settle after installation. Frictional forces develop along the sides of the trench walls as the backfill settles that tend to act upward against the direction of settlement. Narrow trench design utilizes this concept to
reduce earth loads on the pipe. As the trench width at the top of the pipe gets wide, the positive effect of the frictional forces is diminished until the transition trench width is achieved. This effectively negates the positive effect of the trench friction forces. When this occurs, the wide trench or embankment design is utilized. As often is the case, pipe trenches get “laid back” to provide safe working conditions, resulting in trench widths well over twice the pipe diameter.

In recognition of construction realities, sloughing and lack of control over trenching, the AWWA DIP and steel pipe design methods utilize the wide width trench designs even if the pipe is to be installed in a trench box. This makes for easy calculation of the earth loads for steel (Equation 7) and DIP (Equation 8). Both equations produce identical results but with different units.

\[ W_c = w B_c H_c \]  \hspace{1cm} \text{Equation 7}

Where:
- \( W_c \) = dead load on the conduit (lb/lin ft of pipe)
- \( H_c \) = height of fill above the top of the pipe (ft)
- \( B_c \) = outside diameter of pipe (ft)
- \( w \) = Soil weight (120 pcf)

\[ P_e = w H/a \]  \hspace{1cm} \text{Equation 8}

Where:
- \( P_e \) = Earth load (psi)
- \( w \) = Soil weight (120 pcf)
- \( H \) = Height of fill above the top of the pipe (ft)
- \( a \) = Conversion factor (144 for psf to psi)

Concrete pressure pipe generally utilizes the Marston theory to determine earth loads (Equation 9), which recognizes the frictional forces in an ideal trench condition. It is the opinion of the author that wide trench or embankment design should be utilized for all pipe materials and the benefits of a trench installation as a safety factor against construction inconsistencies.

\[ W_d = C_d w B_d^2 \]  \hspace{1cm} \text{Equation 9}

Where:
- \( W_d \) = Trench fill load (lb/lin ft of pipe)
- \( w \) = Unit wt of fill material (pcf)
- \( B_d \) = Width of trench at top the pipe (ft)
- \( C_d \) = Trench load coefficient

**Live loads** are those generally imposed by trucks, railroads or construction equipment. In general, HS-20 loaded trucks with covers of 4 feet or greater over the pipe should have limited impact on the pipe. Railroad and heavy construction equipment such as scrapers or off-road trucks require analysis of each pipe type to determine the required minimum cover over the pipe needed to minimize live loads. Reference the AWWA design guides for additional information on job-specific scenarios.
**Bedding and Backfill.** Stable foundations for the pipe and backfill zones, yielding select bedding material, proper haunching of backfill materials (no voids) and compacted side fill are important for all pipe materials. For rigid pipe, the bedding provides a uniform surface to transfer the pipe loads (from internal and external pressures) in the pipe wall into the soil. The angle of contact with the bedding determines the bedding angle for design. Experience has shown that a 30- to 60-degree bedding angle is specified. Flexible pipe requires a combination of soil stiffness and pipe wall stiffness to support earth loads. It is more cost effective and less costly to specify higher soil stiffness (better material or higher compaction level) than pipe wall stiffness or thickness. The soil stiffness, or Modulus of Soil Reaction (E’), is noted in Table 2.

**Table 2:** Modulus of Soil Reaction, E’ (psi) from AWWA M11 Table 6-1

<table>
<thead>
<tr>
<th>Native Soil Type</th>
<th>Depth of Cover (ft)</th>
<th>85%</th>
<th>90%</th>
<th>95%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Coarse-grained soils with little or no fines</td>
<td>2-5</td>
<td>700</td>
<td>1000</td>
<td>1600</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>1000</td>
<td>1500</td>
<td>2200</td>
<td>3300</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>1050</td>
<td>1600</td>
<td>2400</td>
<td>3600</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>1100</td>
<td>1700</td>
<td>2500</td>
<td>3800</td>
</tr>
<tr>
<td><strong>B</strong> Coarse-grained soils with fines (SM, SC)</td>
<td>2-5</td>
<td>600</td>
<td>1000</td>
<td>1200</td>
<td>1900</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>900</td>
<td>1400</td>
<td>1800</td>
<td>2700</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>1000</td>
<td>1500</td>
<td>2100</td>
<td>3200</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>1100</td>
<td>1600</td>
<td>2400</td>
<td>3700</td>
</tr>
<tr>
<td><strong>C</strong> Fine-grained soils with less than 25% coarse-grained particles (CL, ML, CL-ML)</td>
<td>2-5</td>
<td>500</td>
<td>700</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>600</td>
<td>1000</td>
<td>1400</td>
<td>2000</td>
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<tr>
<td></td>
<td>10-15</td>
<td>700</td>
<td>1200</td>
<td>1600</td>
<td>2300</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>800</td>
<td>1300</td>
<td>1800</td>
<td>2600</td>
</tr>
</tbody>
</table>

A specifier can choose an E’ value from this table or provide bedding and backfill detail along with compaction requirements. All materials listed are suitable for backfilling flexible pipe if the compaction requirement is feasible. The Spangler equation is commonly used to predict deflection in a flexible pipe. AWWA Design Guides limit deflection to 3% for both cement lined ductile iron pipe and steel pipe. BWCCP deflection is limited to D*2/4000. Ductile iron pipe also checks ring-bending stresses. A deflection lag factor of 1.0 is used in the Spangler Equation (Equation 10) for pressurized lines by the concrete pressure pipe, ductile iron and steel industries. Additionally, allowable deflection limits for various linings and coatings are listed in Table 3. Table 4 details maximum fill height for steel pressure class pipe with variable E’ utilizing ASTM A139 Grade C steel with 42,000 psi minimum yield. E’ values to 3,000 psi are available with the use of crushed stone bedding and backfill.
\[ \Delta_x = D_l \left( \frac{KWr^3}{EI + 0.061E'r^3} \right) \]  

Equation 10

Where:
\( \Delta_x \) = Horizontal deflection of pipe (in.)
\( D_l \) = Deflection lag factor (1.0 with 85% or greater compaction)
\( K \) = Bedding constant (0.1)
\( W \) = External Load per unit of pipe length (lb./linear in. of pipe)
\( r \) = Pipe Radius (Cylinder OD/2 in inches)
\( EI \) = Pipe wall stiffness (lb.-in\(^2\)), where:
- \( E \) = Modulus of elasticity (steel: 30,000,000 psi, cement mortar: 4,000,000 psi)
- \( I \) = Transverse moment of inertia per unit length of pipe wall (in\(^4\)/in)
\( E' \) = Modulus of soil reaction (lb./in\(^2\))

Table 3: Allowable Deflection Limits for Flexible Pipe (and fittings) or Flexible Fittings of Rigid PCCP

<table>
<thead>
<tr>
<th>Lining &amp; Coating</th>
<th>% of Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel pipe mortar lined &amp; flexible coated or DIP</td>
<td>3%</td>
</tr>
<tr>
<td>Steel pipe flexible lined &amp; flexible coated or DIP</td>
<td>5%</td>
</tr>
<tr>
<td>Steel pipe mortar lined &amp; mortar coated</td>
<td>2%</td>
</tr>
<tr>
<td>BWCCP pipe and steel fittings</td>
<td>D*2/4000</td>
</tr>
<tr>
<td>PCCP steel fittings</td>
<td>D*2/4000</td>
</tr>
</tbody>
</table>
### Table 4: Allowable Fill for Mortar Lined and Flexible Coated Steel Pipe

<table>
<thead>
<tr>
<th>Pressure Class</th>
<th>Type 1 (E'=700)</th>
<th>Type 2 (E'=1000)</th>
<th>Type 3 (E'=1200)</th>
<th>Type 4 (E'=1400)</th>
<th>Type 5 (E'=1600)</th>
<th>Type 6 (E'=2000)</th>
<th>Type 7 (E'=3000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>19</td>
<td>24</td>
<td>28</td>
<td>32</td>
<td>35</td>
<td>38</td>
<td>40</td>
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<tr>
<td>200</td>
<td>17</td>
<td>24</td>
<td>28</td>
<td>32</td>
<td>35</td>
<td>38</td>
<td>40</td>
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<tr>
<td>225</td>
<td>18</td>
<td>24</td>
<td>29</td>
<td>33</td>
<td>37</td>
<td>40</td>
<td>43</td>
</tr>
<tr>
<td>250</td>
<td>19</td>
<td>25</td>
<td>29</td>
<td>34</td>
<td>39</td>
<td>42</td>
<td>46</td>
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<tr>
<td>300</td>
<td>19</td>
<td>26</td>
<td>30</td>
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<td>39</td>
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<td>36</td>
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<tr>
<td>42</td>
<td>17</td>
<td>23</td>
<td>28</td>
<td>32</td>
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<td>44</td>
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<tr>
<td>48</td>
<td>17</td>
<td>23</td>
<td>28</td>
<td>32</td>
<td>37</td>
<td>44</td>
<td>47</td>
</tr>
</tbody>
</table>

* Table shows select diameters. Diameters are available in 6 inch and larger sizes.

**Buckling**

Above ground or unconfined flexible pipes such as penstocks or siphons can be subject to buckling from vacuum or atmospheric pressures. Buckling design should be provided for above ground installations per appropriate AWWA Design Guides. Buried flexible pipe or fittings should be designed for internal pressure and then checked for buckling. Flexible pipe with backfill properly compacted to a minimum of 85% does not fail in vacuum as the compacted backfill in the pipe embedment zone will resist pipe wall movement. Movement in the pipe wall and supporting backfill is required for buckling to occur. Compacted backfill material in the pipe embedment zone resists this movement. This combined with the common use of air/vacuum release valves provides redundancy.
Handling

A handling check is required for steel pipe to make sure the wall thickness required for internal pressures, external loads and buckling is sufficient to assure proper handling. M11 requires the following wall thickness (t) check for flexible coated and or lined steel pipe with D = Inside Diameter (ID).

\[ t = \frac{D}{288} \text{ for pipe up to 54 in. ID} \]  \hspace{1cm} \text{Equation 11}

\[ t = \frac{(D + 20)}{400} \text{ for pipe greater than 54 in. ID} \]  \hspace{1cm} \text{Equation 12}

\[ t = \frac{D}{240} \text{ for cement lined} \]  \hspace{1cm} \text{Equation 13}

Jointing

All materials utilize a gasketed push-joint as the primary connection. Restrained joints for Steel pipe are generally single weld lap-welds. Welded joints develop the full thrust capability of the pipe wall and provide the surest restrained joint. DIP utilizes a number of proprietary mechanical systems to provide restraint (see M41). Concrete pressure pipe also provides proprietary mechanical restraining systems or field welding of joint rings (see M9). The calculation of thrust and the resulting restrained joint length calculations are different for each product and are the center of much discussion. Tying sufficient lengths of pipe on either side of a valve, bulkhead or fitting resists the thrust (or PA). The length of the restrained pipe is determined by the dead weight of the pipe filled with water, the overburden and the friction forces of the pipe pulling through the soil. There are differences in the weight and coefficient of friction of the pipe materials providing different variables in the restrained length calculation. The restrained length formula should be consistent for all products on each project with suggested formulas and coefficients of friction following:

\[ \text{Determination of Thrust at bends or elbows} \]

\[ T = 2PA \left( \sin \frac{\Delta}{2} \right) \]  \hspace{1cm} \text{Equation 14}

Where:

- \( T \) = Thrust in lbs.
- \( P \) = Design pressure \((P_w + P_t)\) in psi
- \( A \) = Cross-sectional area of the pipe in \( \text{in}^2 \)
- \( \Delta \) = Bend or deflection (for valves, tees, and bulkheads use 90 degrees)

\[ \text{Determination of Restrained Joint Length} \]

\[ L = \frac{(PA (1-\cos \Delta))}{(\mu(2W_c + W_w + W_p))} \]  \hspace{1cm} \text{Equation 15}

Where:

- \( L \) = Length of restrained or harnessed joints on each side of the bend
- \( P \) = Design pressure \((P_w + P_t)\) in psi
- \( A \) = Cross-sectional area of the pipe in \( \text{in}^2 \)
- \( \Delta \) = Bend or elbow deflection
- \( \mu \) = Coefficient of friction between pipe and soil (concrete surface 0.35, tape or polyethylene coated surface 0.32, painted surface 0.25)
- \( W_c \) = Weight of prism of soil over the pipe (lb./ft of pipe length)
- \( W_p \) = Weight of pipe (lb./ft)
- \( W_w \) = Weight of contained water (lb./ft)
Corrosion Control or Protection

“In 2000, the Water Infrastructure Network estimated that costs of corrosion for drinking water systems only were estimated at $19.95 billion per year in the US. Although most agencies address corrosion on the inside of pipes with linings, corrosion on the outside of pipes often is addressed with a less-than-scientific approach.” With this background, it is apparent that for preservation of waterworks infrastructure and investment, proper design requires adequate corrosion protection. Corrosion can be prevented; however, varying opinions on the matter exist among the ferrous-based pipe producers and corrosion protection industry. Some specifiers add sacrificial metal or “corrosion allowance” to pipe in an effort to add service life or corrosion control. As the M41 Section 10.6.5 states, “increasing wall thickness to allow sacrificial metal loss is totally unscientific because there is no assurance that corrosion will attack the pipe wall uniformly. Instead, corrosion attack may occur in the form of localized pitting, which can result in premature failure of the pipe by perforation, regardless of wall thickness. In addition to being unreliable, the practice of increasing pipe wall thickness as a safeguard against corrosion is also not cost-effective.”

Each product’s industry has its own practices to address corrosion in buried pipe. Concrete pressure pipe utilizes ¾-inch of cement-mortar coating over the bare prestressing wire or steel bar. Passivation of the steel by the high ph concrete provides protection from galvanic corrosion when there is intimate contact between mortar and steel components. However in areas of corrosive soils, damaged coating or stray currents additional protection may be needed. The American Concrete Pressure Pipe Association recommends bonded joints and test stations. External barrier coatings over the concrete coatings have also been used as well as cathodic protection to provide long term corrosion protection.

Ductile iron pipe’s standard product is coated with a one mil asphaltic paint and service life is primarily dependent on the thickness of the pipe wall. The service life of the thicker cast iron pipe of the early 1900’s provides the basis for much of the service life projections of today’s ductile iron pipe. These service life projections may not be justified due to reductions in thickness of 68% to 75% (see Figure 1). Field applied unbonded polyethylene encasement is recommended by DIPRA for added corrosion control. Ductile iron can be coated with tightly bonded dielectric coatings such as polyurethane, epoxy and tape as well as cathodic protection for long term corrosion protection.

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Steel pipe is routinely coated with a bonded dielectric coating such as AWWA C214 tape coating system. Other AWWA bonded coatings such as polyurethane, epoxy, and polyurea have been used for corrosion protection. These coatings are applied to a blasted surface and serve as a barrier to corrosive soils and stray electrical currents. Cement-mortar coating is also utilized with the same passivation concept as used for concrete pressure pipe. Steel pipe, like concrete pressure pipe, endorses the use of bonded joints on gasketed pipe and test stations to monitor potential current flow (corrosion) in the pipe. Cathodic protection can also be used in conjunction with cement-mortar or bonded dielectric coating systems.

Initial corrosion control for all ferrous based pipes can be as simple as bonding gasketed joints with test stations to make the pipeline continuous and allow the monitoring of the corrosion activity. This process is inexpensive and allows for the addition of a cathodic protection system later if needed. Insulating joints should also be incorporated as needed. Cathodic protection systems can be used to provide long term corrosion protection to ferrous surfaces or supplement unbonded or bonded mortar or dielectric protective coatings. A corrosion engineer generally designs the cathodic protection systems.

**Determining Acceptable Risk**

Determining risk is the first step in the design of corrosion protection. To effectively design a pipe system, an owner must establish a risk level for the design. The consultant should work with the owner to answer questions like these: How comfortable is the owner with a 25 to 32 year service life for a community’s only 48-inch raw water line? On the other hand, how comfortable is the owner with a 25 to 32 year life of 6-inch distribution pipe? Refer to Table 5 for corrosion protection levels.
Table 5: Current Corrosion Control and/or Protection Levels for Pipe

<table>
<thead>
<tr>
<th>Level</th>
<th>Control or Protection Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>No protection, pipe installed bare without monitoring system</td>
</tr>
<tr>
<td>Level 2</td>
<td>Install pipeline bare with polyethylene encasement, without monitoring system</td>
</tr>
<tr>
<td>Level 3</td>
<td>Level 2 + monitoring system (bonded joints and test leads)</td>
</tr>
<tr>
<td>Level 4</td>
<td>Bonded dielectric or cement-mortar coatings without monitoring system</td>
</tr>
<tr>
<td>Level 5</td>
<td>Level 4 + monitoring system (bonded joints and test leads)</td>
</tr>
<tr>
<td>Level 6</td>
<td>Level 3 or 5 + cathodic protection</td>
</tr>
</tbody>
</table>

Once the level of acceptable risk is determined, the appropriate AWWA coating standards can be specified according to the acceptable level of risk. Once the risk level is determined it is important that all ferrous based products be protected at the same level to assure equal performance levels and useful life of the pipeline. Independent corrosion engineers are generally consulted for the entire corrosion evaluation and recommendation process.

Conclusion

Utilization of the Pressure Class Design concept for the specification of transmission pipe materials is an effective way to provide consistent performance based specifications utilizing proven AWWA design guidelines and standards. There is normally no need to prepare multiple designs for multiple products. If more conservative specifications are needed, do so by requiring a higher Pressure Class (in multiples of 25 psi) for all pipe materials. Pressure Class designs and specifications will provide competition and assure the owner’s needs are met with the least amount of risk.

Recommended steps for the design and specification of equal performance pressure class pipe materials:

1. Reference AWWA M9, M11 and M41 design guidelines along with appropriate AWWA standards.
2. Determine working and surge or transient pressures.
3. Specify minimum design working, surge and test pressures.
4. Specify a minimum height of cover for design and use the wide trench or embankment earth load design method.
5. Provide an E’ value or a bedding and backfill detail for both flexible and rigid pipe.
6. Provide bedding angle for rigid pipe design.
7. Provide equal corrosion protection requirements and cathodic protection design (as required) for the appropriate risk level.
8. Provide uniform equations for determination of thrust and restrained joint lengths.
References


