

## **Corrosion Protection Provided by Mortar Lining in Large Diameter Water Pipelines After Many Years of Service**

Sylvia C. Hall, P.E., M.ASCE<sup>1</sup>

### **Abstract**

More than 95% of large diameter steel (AWWA C200/C205), ductile iron (AWWA C104), and concrete cylinder pipelines (AWWA C303) used in water transmission contain a portland cement mortar lining that protects the interior steel or iron surface from corrosion. This lining has been used in water pipelines for at least 175 years. The mortar provides protection due to the highly alkaline environment produced by the hydration of portland cement which passivates the interior metal surface of the pipe.

During the past 30 years, the mortar linings from numerous concrete cylinder pipelines and steel pipelines after up to 108 years of service were evaluated to determine their condition. Properties such as absorption, specific gravity, and compressive strength and the available alkalinity, pH, and chloride ion content through the thickness of the linings were determined. The amount of leaching or carbonation found in the mortar lining was related to the various constituents in the water transported and to the mortar's absorption. Visual observation of the steel cylinder for the presence of corrosion was also made and related to the condition of the mortar lining. The test results of these case histories are presented and discussed.

### **Introduction**

Portland cement mortar linings are used in steel and ductile iron pipe in the water industry primarily to protect the interior surface from the corrosive action of the transported water. The mortar provides protection due to the highly alkaline environment produced by the hydration of portland cement which passivates the interior metal surface of the pipe.

The history and performance of mortar linings in water pipelines have been extensive and excellent for more than 100 years (Bardakjian 1995, Bardakjian and Hausmann

---

<sup>1</sup> Director, Engineering Development Center, NOV Ameron, 8627 Atlantic Ave, South Gate, CA 90280, PH (323) 564-6626; FAX (323) 563-8208; e-mail: [Sylvia.Hall@nov.com](mailto:Sylvia.Hall@nov.com)

2007, AWWA C205 2012). One of the first mortar-lined and -coated steel pipelines in North America was installed in the City of St. John, New Brunswick, Canada in 1855. A section of the pipeline, which transported relatively aggressive potable water, was removed from service due to line relocation in 1963 after 108 years of service and the interior and exterior was found to be free of corrosion (Bardakjian 1995, Bardakjian and Hausmann 2007). Cement-mortar-lined and -coated steel pipe was first used in the United States in the late 1800s. Some of the first pipelines were in service for almost a century by the time the first national standard was written in 1941 (AWWA C205 2012).

Besides being used on steel pipe, the need for a better lining to combat tuberculation at pinholes of hot-dip bituminous-lined cast-iron pipe led to the first use of portland cement mortar linings in cast-iron pipe in 1922 (AWWA C104 2008).

Portland cement mortar is the predominant lining system for steel, cast-iron, and ductile-iron water pipelines. Portland cement mortar or portland cement concrete is always used as the lining system in concrete pressure pipe. Use of mortar lining in water transmission steel pipelines for at least the past 50 years is estimated at greater than 95%. The remaining small percentage of steel water pipelines that do not use portland cement lining systems are typically penstocks and above-ground pipelines.

Mortar linings consist of 1 part ASTM C150 portland cement to not more than 3 parts ASTM C33 fine aggregate (sand) by weight. The mortar is applied in the vast majority of cases in a manufacturing facility by rotating the pipe and centrifugally applying the mortar as shown in Photograph 1. For very large diameter pipe that cannot have the lining applied in a manufacturing facility, the pipe can be mortar lined by other methods after installation.



**Photograph 1. Mortar lining manufacturing process.**

### Thickness of Mortar Linings

The minimum or nominal thicknesses of mortar lining for steel pipe (AWWA C205 2012), ductile iron pipe (AWWA C151 2009), and concrete cylinder pipe (AWWA C303 2008) are given in Table 1.

**Table 1**  
**Thickness of Mortar Lining in Water Pipelines**

| Pipe Type                    | AWWA Standard | Diameter Range, inch (mm) | Nominal Lining Thickness, inch (mm) |
|------------------------------|---------------|---------------------------|-------------------------------------|
| Steel Pipe                   | C205          | 4 to 10 (100-250)         | 1/4" (6)                            |
|                              |               | 11 to 23 (275-575)        | 5/16" (8)                           |
|                              |               | 24 to 36 (600-900)        | 3/8" (10)                           |
|                              |               | Over 36 (over 900)        | 1/2" (13)                           |
| Ductile Iron Pipe            | C151/C104     | 3 to 12 (76-305)          | 1/16" (1.6) min.                    |
|                              |               | 14 to 24 (356-610)        | 3/32" (2.4) min.                    |
|                              |               | 30 to 64 (762-1600)       | 1/8" (3.2) min.                     |
| Concrete Cylinder Pipe (CCP) | C303          | 10 to 16 (250-400)        | 1/2" (13)                           |
|                              |               | 18 to 72 (450-1830)       | 3/4" (19)                           |

### Method of Corrosion Protection

Portland cement mortar linings protect steel from corrosion by a process called passivation. Portland cement consists of calcium oxide and small quantities of potassium and sodium ions that convert to calcium, potassium, and sodium hydroxides when water is added to the cement and sand mix during pipe manufacture. This hydration produces a high pH environment greater than 12.5. At these levels, steel passivates and does not corrode. The passivation effect of portland cement has been known for at least 100 hundred years (Rosa et al 1913). Water and oxygen diffusion through the mortar does not reduce passivation of the steel.

### Water Absorption

The vast majority of potable water does not harm portland cement mortar linings. In fact, water promotes further hydration and strength development of mortar. In most waters, mortar linings allow for autogenous healing of cracks due to a chemical reaction between the bicarbonate ions in the water and the calcium and hydroxide ions in mortar. In addition, water within the microscopic pores in the mortar slows the diffusion of air (oxygen) to the steel surface that is required for corrosion, allowing mortar lining to continue to protect steel even if all excess alkalinity (hydroxide ions) is leached or carbonated.

### **Available Alkalinity and pH**

One way to determine whether the mortar lining is being leached or carbonated is to determine the amount of hydroxide ions present. Measuring pH is one way to measure hydroxide ions but this only measures the ions in solution. Solid calcium hydroxide is also present in mortar and measuring the available alkalinity provides a way to quantitatively determine the reserve basicity or excess alkalinity “available” to passivate steel and protect it from corrosion if leaching or carbonation occurs.

### **Test Pipe Evaluated and Test Procedures**

During the past 30 years, mortar-lined steel pipe (AWWA C205) and concrete cylinder pipe (AWWA C303) sections were removed from service and their condition evaluated after 20 to 108 years transporting waters of various compositions. The chemical composition of the water transported was obtained from the water agency in many cases.

Mortar linings were removed from the pipe sections and absorption and specific gravity were determined in accordance with ASTM C497, method A and ASTM C642, respectively. Cube compressive strengths were determined in accordance with AWWA C301, section 4.6.8.5.

The linings were layered in 1/16” (1.6 mm) depth increments and water-soluble chloride content, available alkalinity, and pH were determined in select layers. Water soluble chloride content was determined in accordance with AASHTO T260. Available alkalinity, expressed as percent calcium hydroxide, was determined by weighing 0.10 g of the powdered mortar, adding 500 ml of deionized water, leaching for 24 hours, filtering, and titrating the filtrate with a standardized 0.10 N sulfuric acid solution to the phenolphthalein endpoint. The pH was determined by mixing 1 gram of the powdered mortar with 1 ml of deionized water, allowing the mixture to stand for 1 hour, and then measuring the pH using a “sodium-ion-error-free” pH electrode. The use of this type of pH electrode reduces the pH depression measurement error caused by sodium ions when present in high pH solutions. Sodium ions can contaminate mortar when deicing salts (sodium chloride) are used, in marine environments, and in high-chloride containing soils or waters.

### **Test Results**

Table 2 shows the pipe type, diameter, location, years of service, various constituents of the water transported (pH, hardness, chloride and sulfate content), and absorption, specific gravity, cube compressive strength, and chloride ion content of the mortar linings.

The inner diameters of the pipe sections evaluated ranged from 12 to 54 inches and the years in service ranged from 20 to 108. The pipe sections were predominately from California, Washington, Arizona, and Oregon with one pipe from New

**TABLE 2  
ABSORPTION, SPECIFIC GRAVITY, CUBE COMPRESSIVE STRENGTH, AND CHLORIDE CONTENT  
OF MORTAR LININGS AFTER MANY YEARS OF SERVICE**

| Pipe Type | Inner Diameter, inch | Location            | Years of Service | Water Constituents |                                    |                |               |   | Absorption, % | Specific Gravity (SSD) | Cube Compressive Strength, psi | Chloride Content Range in Lining, mg/kg |
|-----------|----------------------|---------------------|------------------|--------------------|------------------------------------|----------------|---------------|---|---------------|------------------------|--------------------------------|---|
|           |                      |                     |                  | pH                 | Hardness, ppm as CaCO <sub>3</sub> | Chloride, mg/l | Sulfate, mg/l | Description   |               |                        |                                |   |
| CCP       | 30                   | Tucson              | 21               | >6.5               | 400-696*                           | 200-500        | 260-750       | High CO <sub>2</sub> well water (10-1140 mg/l CO <sub>2</sub> ) | 11.9          | 2.27                   | 8030-9470                      | 120-2000                                |
|           | 24                   |                     |                  |                    |                                    |                |               |   | 13.0          | 2.28                   | 4680-7740                      | 80-750                                  |
|           | 30                   |                     |                  |                    |                                    |                |               |   | 11.5          | 2.29                   | 5890-6430                      | 80-1700                                 |
|           | 24                   |                     |                  |                    |                                    |                |               |   | 11.9          | 2.29                   | 3350-4930                      | 80-300                                  |
|           | 30                   |                     |                  |                    |                                    |                |               |   | 8.7**         | 2.36                   | 6040-6550                      | 150-1900                                |
| CCP       | 30                   | Santa Ynez, CA      | 32               | 7.8                | 332                                | 13             | 224           | Hard Water  | 9.0           | 2.36                   | ND                             | ND                                      |
|           |                      |                     |                  |                    |                                    |                |               |   | 7.1           | 2.41                   | ND                             | ND                                      |
|           |                      |                     |                  |                    |                                    |                |               |   | 7.6           | 2.42                   | ND                             | ND                                      |
|           |                      |                     |                  |                    |                                    |                |               |   | 7.5           | 2.41                   | ND                             | ND                                      |
| Steel     | 24                   | Phoenix             | 60               | NA                 | NA                                 | NA             | NA            | NA  | 5.9           | 2.45                   | ND                             | 125-1100                                |
| CCP       | 16                   | Phoenix             | 40               | NA                 | NA                                 | NA             | NA            | NA  | 7.24          | 2.39                   | 8580-9230                      | 250-900                                 |
| Steel     | 48                   | East Bay, CA        | 27               | NA                 | NA                                 | NA             | NA            | NA  | 9.6           | 2.34                   | 8460-9040                      | 20-50                                   |
| CCP       | 15                   | Ocean Outfall, OR   | 24               | 7-8                | NA                                 | 30,000         | 2800          | Sea Water   | 7.6           | 2.40                   | 8530-8960                      | 2000-12,500                             |
| CCP       | 20                   | New Mexico          | 30               | NA                 | NA                                 | NA             | NA            | Snow melt, soft water   | 9.5-9.8       | 2.33                   | 7720-9350                      | 200-480                                 |
| CCP       | 54                   | Seattle             | 20               | 6.9                | 9.7                                | 0.5            | 3             | Soft  | 13.8-14.1     | 2.26-2.27              | 7100-9850                      | 20-150                                  |
| CCP       | 30                   | Alameda, CA         | 20               | 8.1                | 46                                 | 14             | 5             | NA  | 7.7-8.0       | 2.40                   | 11,500-12,600                  | 10-180                                  |
| NA        | NA                   | So. CA              | 30               | NA                 | NA                                 | NA             | NA            | Hard  | 5.2           | 2.47                   | 17,300                         | ND                                      |
| NA        | NA                   | Hetch Hetchy, CA    | 30               | 8.3                | 42                                 | NA             | NA            | Soft water with Lime  | 10.3          | 2.29                   | 7920-9650                      | ND                                      |
| Steel     | 12                   | St John, NB, Canada | 108              | 6.8                | 10                                 | 11             | NA            | Aggressive, soft water  | 36.4          | 1.8                    | ND                             | ND                                      |
| CCP       | 24                   | Skagit, WA          | 48               | NA                 | NA                                 | NA             | NA            | NA  | 11.1-13.7     | 2.30-2.40              | 7810-10,100                    | 0-100                                   |
| CCP       | 21                   | Astoria, OR         | 48               | NA                 | NA                                 | NA             | NA            | NA  | 12.7-15.6     | 2.24-2.27              | 5130-8640                      | 0-150                                   |
| CCP       | 42                   | Hanford, WA         | 67               | 7.8                | 56                                 | <0.5           | 1             | Soft water  | 7.2-8.0       | 2.34-2.36              | 10,700-15,300                  | 0-20                                    |
| Steel     | 24                   | Hanford, WA         | 67               | 7.8                | 56                                 | <0.5           | 1             | Soft water  | 8.9-12.6      | 2.27-2.37              | 8690-16,100                    | 0-20                                    |

NA = Not Available; ND = Not Determined, \* = Bicarbonate Alkalinity, mg/l as CaCO<sub>3</sub>, \*\* = Laitance missing.

Brunswick, Canada and one from New Mexico. They transported very soft, aggressive waters to very hard waters. One was removed from the end of an ocean outfall which was continuously submerged in seawater and another transported well water that contained high levels of carbon dioxide.

**Absorption, Specific Gravity, and Compressive Strength** – Absorptions ranged from 5.2 to 36.4% with the vast majority ranging from 7.1 to 14.1% and specific gravity ranged from 1.8 to 2.47 with the vast majority ranging from 2.24 to 2.47. Cube compressive strengths ranged from 3,350 psi to 17,300 psi.

**Examination of Steel Cylinder for Corrosion** – Upon examination of the steel cylinder under the mortar linings, the steel was free from corrosion in most cases irrespective of the absorption or compressive strength values or whether the water transported was considered soft or hard or was sea water. Only superficial or insignificant amounts of corrosion were found in the remaining three cases.

**pH Profiles** – The pH profiles through the mortar linings of the pipe sections presented in Table 2 are shown in Figure 1. The typical pH of fresh, cured mortar using the method described in the Test Procedures Section is roughly 12.3 to 12.6 as shown in Figure 1. pH lower than that usually indicates that leaching of hydroxide ions or carbonation has occurred.

**Available Alkalinity Profiles** – The available alkalinity profiles of the mortar lining of the pipe sections described in Table 2 are shown in Figure 2. The typical available alkalinity content of fresh mortar lining is roughly 8% to 10% as expressed as calcium hydroxide  $[\text{Ca}(\text{OH})_2]$  as shown for the freshly-made lining in Figure 2. The available alkalinity is higher at the innermost laitance surface layer (water surface) due to a much higher concentration of small cement particles that are deposited there during the spinning process. The dashed line at 7.25% alkalinity represents a pH of roughly 12.4. The dotted line at 3.75% represents a pH of roughly 11 and an available alkalinity of 0 represents a pH no greater than the low 9's, the phenolphthalein end point. Alkalinity greater than 7.25% represents excess hydroxide ions present in the form of unhydrated portland cement and solid calcium hydroxide in the mortar lining that goes into solution if leaching or carbonation occurs to the hydroxide ions already in solution within pores of the mortar lining.

**Relationship of pH and Available Alkalinity** – The pH and available alkalinity from Figures 1 and 2 are re-plotted in Figure 3 to show their relationship. In general, the pH increases linearly to about 12.3 as available alkalinity increases to 7.25%. At that point the available alkalinity increases while pH is constant. The calcium hydroxide content in cement is the single largest contributor to the pH measured and its maximum solubility at room temperature produces a pH of 12.5.

The pH of a slurry of 1 part mortar to 1 part water, as determined in this paper, is a large dilution of the pore water found in mortar and concrete. The actual pH of the solution within the pores of mortar is roughly 13 to 13.2 when low alkali ASTM

C150 portland cement is used and roughly 13.3 to 13.6 using portland cement with the maximum allowable alkali levels since the small quantities of sodium and potassium ions present will produce higher pH. When pH is determined using 1 part mortar to 1 part water, the small quantities of sodium and potassium hydroxide present are diluted and, as such, are not able to contribute appreciably to the pH measured. Calcium hydroxide is the main contributor to pH using the test method described in this paper. Based on this, the actual pH in the mortar lining layers tested is probably 0.5 to 0.7 pH units greater than reported.

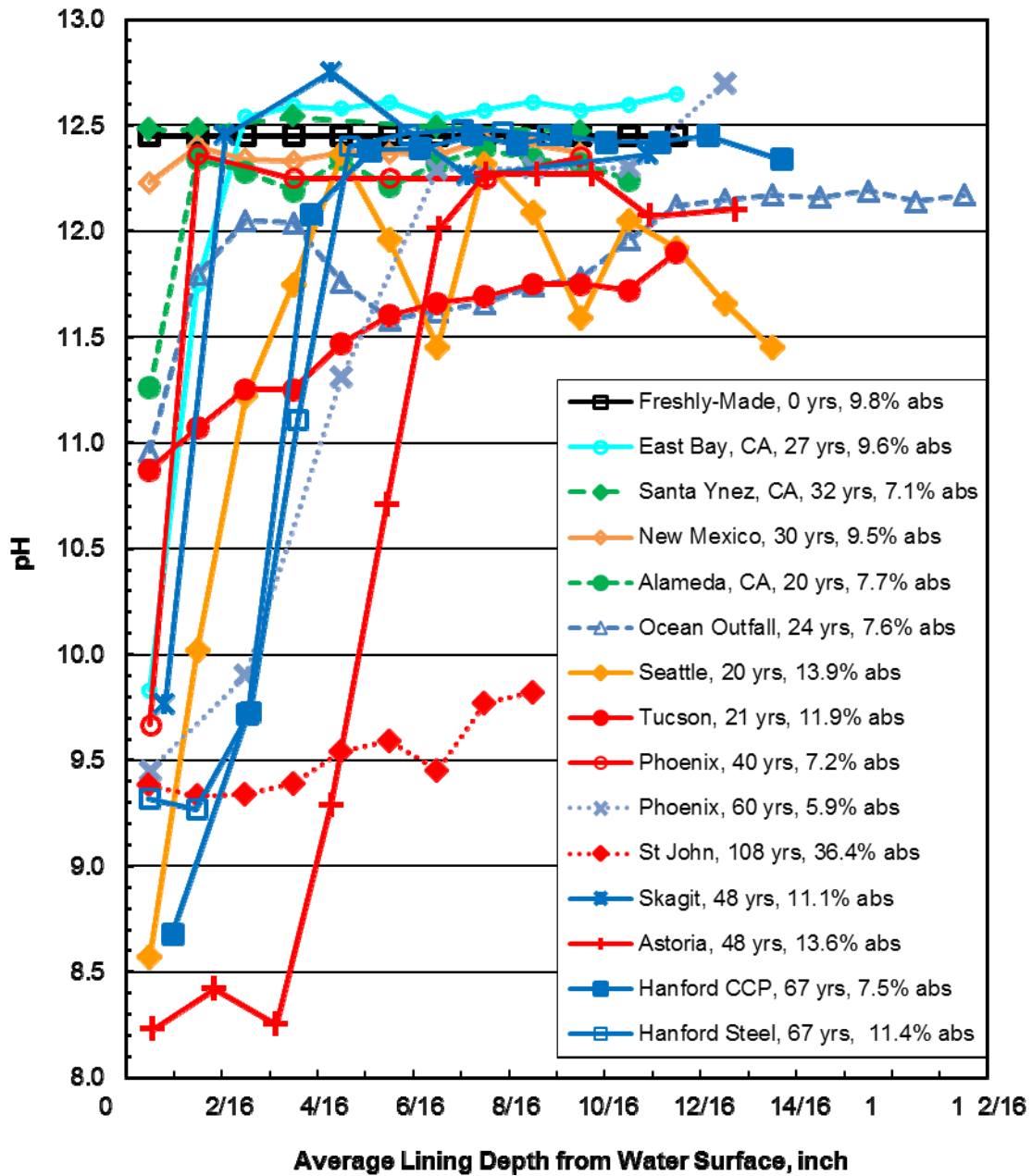


Figure 1. pH profiles of mortar linings after many years of service.

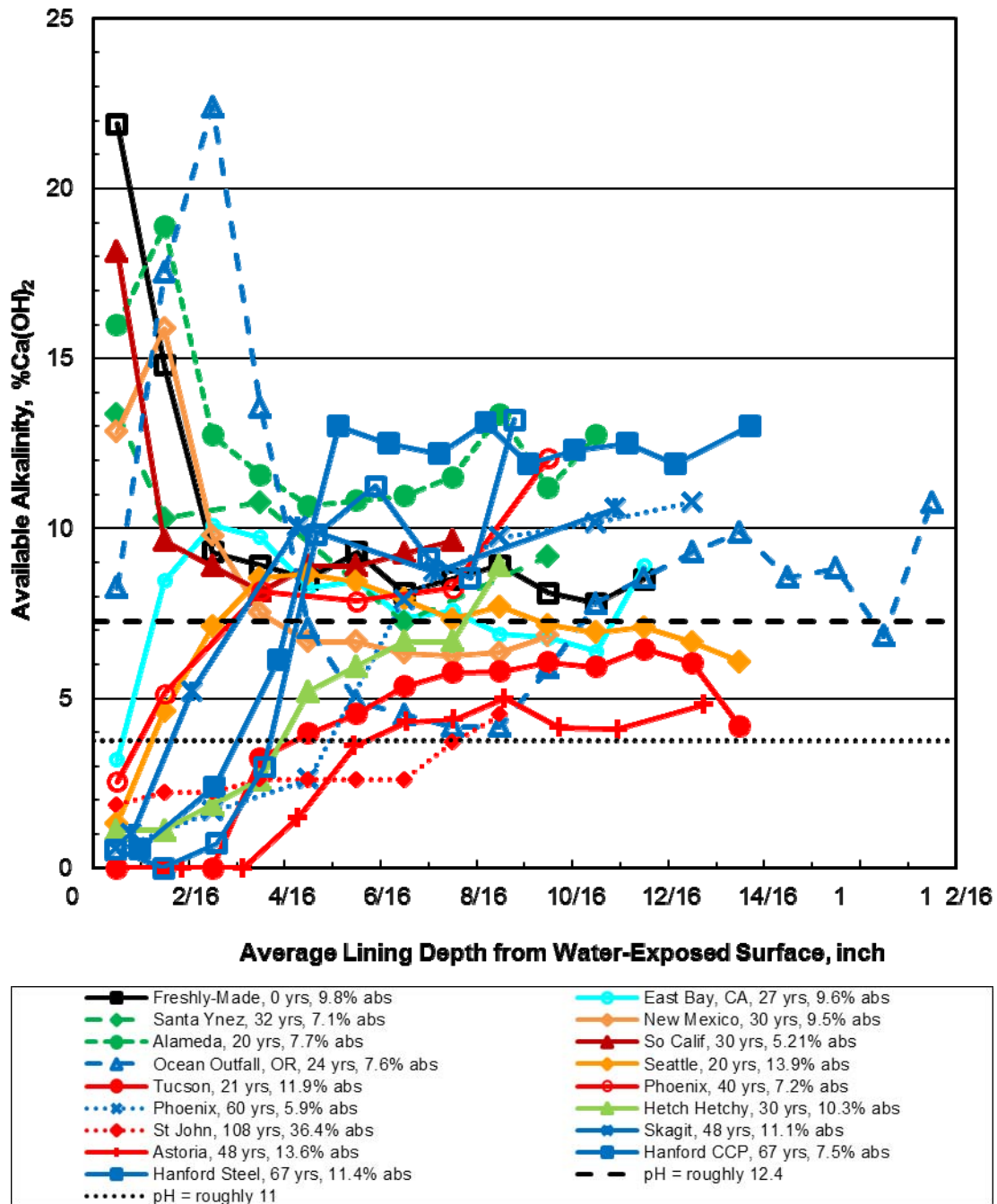
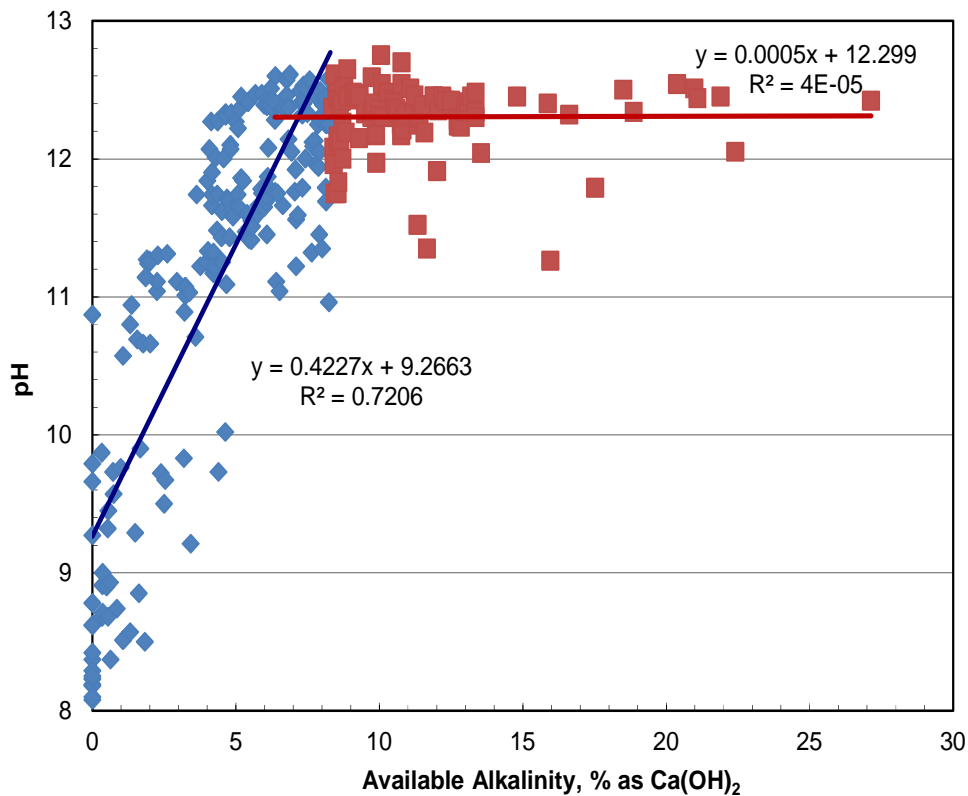


Figure 2. Available alkalinity profiles of mortar linings after many years of service.

**Leaching or Carbonation Rate and Presence of Corrosion on Steel Cylinder** – The leaching or carbonation rates of the mortar linings are given in Table 3. The rate at pH of 12.4 was calculated based on the average depth where the available alkalinity exceeded 7.25% divided by the years of service. This is the point where the pH is roughly 12.4 and solid calcium hydroxide is present. However,



passivation also occurs at a pH of 9 to 11. As such, the leaching or carbonation rate at pH 11 was also calculated based on where the available alkalinity exceeded 3.75%.



**Figure 3. Relationship of pH and available alkalinity in mortar lining.**

Also given in Table 3 is whether corrosion was present on the steel cylinder. In most cases, no corrosion was found on the steel cylinders. Superficial spots of corrosion on the ocean outfall pipe where the chloride ion content in the mortar lining at the steel surface was 3500 mg/kg, immediately surrounding a small diameter unlined tap on the Alameda pipe, and at a mortar lining crack on the Seattle pipe were present but were considered inconsequential. It was also noted that no corrosion was found on the St. John pipe even though available alkalinity and pH were low. This indicates that passivation was still occurring and/or that mortar lining acts as an impediment to the corrosive nature of water and/or the diffusion of oxygen to the steel surface.

**Water Composition** – Select constituents and a general description of the type of water transported, such as soft, hard, or sea water, are given in Table 2. The amount of leaching or carbonation that occurs to mortar linings is influenced by whether the water is considered to be soft or hard. Soft waters are low in ions which can leach out the ions within mortar in its attempt to equilibrate with its surroundings. Hard waters are high in ions and do not tend to leach ions from mortar. High carbon dioxide can react in water to form bicarbonate ions which reacts with the calcium and hydroxide ions in mortar to form calcium carbonate in a carbonation reaction. This

reaction removes hydroxide ions, thus reducing the available alkalinity and pH, and in the long term could depassivate the steel cylinder.

**TABLE 3**  
**LEACHING OR CARBONATION RATE OF MORTAR LININGS**  
**AND PRESENCE OF CORROSION ON STEEL CYLINDER**

| Pipe Type | Inner Diameter, inch | Location            | Years of Service | Leaching or Carbonation Rate (mils/year) and Presence of Corrosion |          |                               |
|-----------|----------------------|---------------------|------------------|--|----------|-------------------------------|
|           |                      |                     |                  | At pH 12.4   | At pH 11 | Presence of Corrosion         |
| CCP       | 30                   | Tucson              | 21               | 40   | 13       | NA                            |
|           | 24                   |                     |                  | 37   | 19       | NA                            |
|           | 30                   |                     |                  | 40   | 16       | NA                            |
|           | 24                   |                     |                  | 25   | 19       | NA                            |
|           | 30                   |                     |                  | 40   | 13       | NA                            |
| CCP       | 30                   | Santa Ynez, CA      | 32               | <1   | <1       | None                          |
|           |                      |                     |                  | <1   | <1       | None                          |
|           |                      |                     |                  | <1   | <1       | None                          |
|           |                      |                     |                  | <1   | <1       | None                          |
| Steel     | 24                   | Phoenix             | 60               | 6.8  | 4.7      | None                          |
| CCP       | 16                   | Phoenix             | 40               | 5.5  | 2.4      | None                          |
| Steel     | 48                   | East Bay, CA        | 27               | 3.5  | 3.5      | None                          |
| CCP       | 15                   | Ocean Outfall, OR   | 24               | 1.3  | 1.3      | Superficial                   |
| CCP       | 20                   | New Mexico          | 30               | <1   | <1       | None                          |
| CCP       | 54                   | Seattle             | 20               | 7.8-14   | 4.7-10.9 | Superficial at mortar crack   |
| CCP       | 30                   | Alameda, CA         | 20               | 1.6  | 1.6      | Superficial at small pipe tap |
| NA        | NA                   | So. CA              | 30               | <1   | <1       | NA                            |
| NA        | NA                   | Hetch Hetchy, CA    | 30               | 18   | 9.4      | NA                            |
| Steel     | 12                   | St John, NB, Canada | 108              | 4.9  | 4.3      | None                          |
| CCP       | 24                   | Skagit, WA          | 48               | 5.6-16   | 2.7-8.6  | None                          |
| CCP       | 21                   | Astoria, OR         | 48               | 16   | 7.1      | None                          |
| CCP       | 42                   | Hanford, WA         | 67               | 4.8  | 3.6      | None                          |
| Steel     | 24                   | Hanford, WA         | 67               | 4.4  | 3.3      | None                          |

NA = Not Available.

## Discussion

The following summarizes the evaluation of the mortar linings evaluated in this paper as it relates to the amount of leaching or carbonation that occurred to the mortar lining and its relationship to mortar absorption, water composition, and amount of corrosion that occurred.

**No Leaching or Carbonation** - The mortar linings from the East Bay (27 yrs), Santa Ynez (32 yrs), New Mexico (30 yrs), Alameda (20 yrs), and Southern California (30 yrs) pipe sections maintained the high pH and available alkalinity throughout the entire thickness of the lining during their 20 to 40 years of service. The leaching or carbonation rates were less than 1.6 mils/year for these mortar linings, except for the East Bay lining, and is considered the detection limit for the test method. The values show that, except for the 1/16-inch thick laitance layer in

several of the pipe sections, no leaching or carbonation occurred throughout the entire thickness. This indicates an almost infinite life in the mortar lining's ability to passivate the steel cylinder. Two of the pipe sections (Santa Ynez and Southern California) were known to be transporting hard water and it was suspected that the Alameda pipe was also transporting hard water although Alameda also has soft water sources. The East Bay pipe is suspected of transporting soft water and the New Mexico pipe was reportedly transporting soft water from snow melt.

**Partial Leaching or Carbonation** – The mortar linings from the Phoenix (40 and 60 yrs), Seattle (20 yrs), Tucson (21 yrs), Hetch Hetchy (30 yrs), Skagit (48 yrs), Astoria (48 yrs), and Hanford (67 yrs) pipe sections showed partial leaching or carbonation through the first 3/16- to 3/8-inch layer. In the case of the 60-yr old Phoenix mortar lining, partial leaching or carbonation occurred 3/8" through the lining but maintained a pH of 12.4 to 12.7 and typical alkalinity values in the inner most layers. Assuming a linear leaching or carbonation rate, the pH and alkalinity of the lining at the steel surface of 13/16" would be maintained for more than twice the service period of 60 years, or 120 years total. However, it is theorized that the leaching or carbonation rate slows with time which would produce longer service lives.

In the case of the 67-yr old Hanford CCP mortar lining, partial leaching or carbonation occurred in the first 1/4" layer with no leaching or carbonation in the inner 1/2-inch layers. Assuming a linear leaching or carbonation rate, the pH and alkalinity in the lining at the steel surface of 7/8 inch would be maintained for more than three times the service period of 67 years, or about 200 years total.

The available alkalinity profile of the 30-yr old Hetch Hetchy mortar lining indicates moderate leaching or carbonation occurred to the first 1/4" layer but leveled off at 6 to 7% calcium hydroxide in the remaining 1/4" layer adjacent to the steel cylinder. As such, assuming a constant rate, the pH and alkalinity at the steel surface would be maintained for twice the service period of 30 years, or 60 years total. The water transported is a snow melt in which lime was reportedly added to increase the pH after the first 10 years of service. The addition of lime after the initial 10 years could slow any leaching or carbonation that may occur, and as such, the rate has probably decreased, if not stopped, during the latter 20 years of service.

**Complete Leaching or Carbonation** – The pH and available alkalinity profiles of the 108-yr old St. John mortar lining were the lowest of all of the mortar lining samples. This pipe transported very aggressive waters with a hardness of 10 ppm as CaCO<sub>3</sub> and a pH of 6.8. Although the lining was considerably leached or carbonated throughout its thickness, no corrosion was found on the steel cylinder indicating that sufficient hydroxide ions were present to passivate the steel and/or the mortar lining acted as an impediment to substantially reduce oxygen from diffusing to the steel surface where it is required for corrosion to occur.

**High Carbon Dioxide Well Water** – The pH and available alkalinity profiles of the 21-yr old Tucson mortar lining indicate substantial leaching or carbonation has occurred throughout the lining. The well water transported contained high levels of carbon dioxide (10 to 1140 mg/l) at times which probably partially carbonated the mortar lining. The chloride content of the water also was high and ranged from 200 to 500 mg/l. The chloride content of the mortar lining ranged from 80 to 2000 mg/kg. The leaching or carbonation rate of the five mortar lining samples ranged from 25 to 40 mils/year, the highest of all of the mortar lining samples.

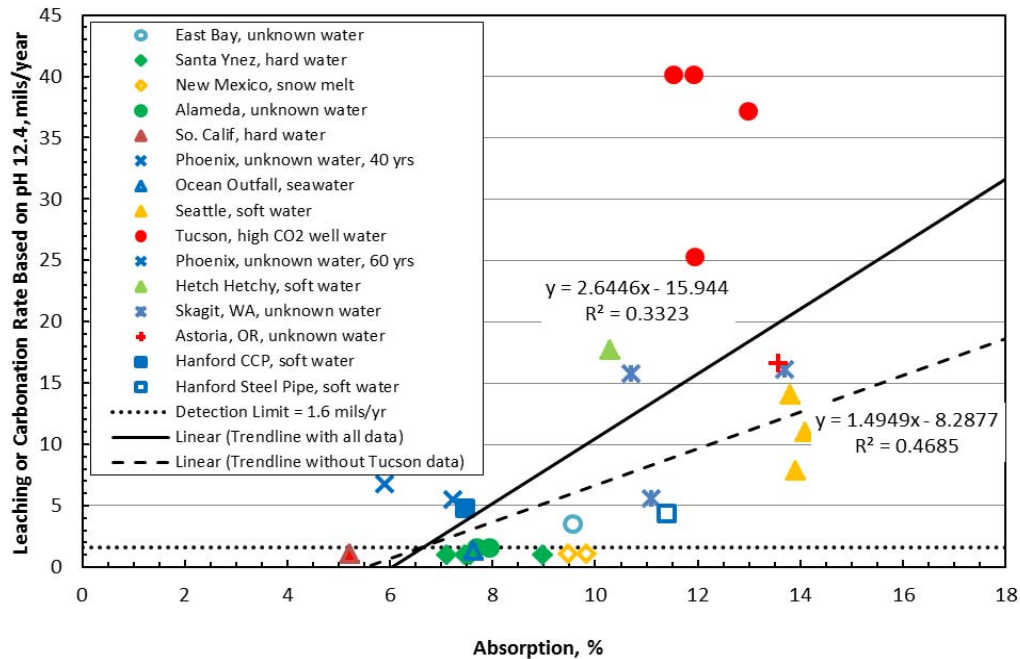
**Sea Water** – The available alkalinity profile of the 24-yr old ocean outfall pipe indicates moderate leaching or carbonation only in the first 1/8” layer yet the pH did not increase to roughly 12.4 as would be expected. However, it is known that sodium ions in high pH solutions can produce an error in pH electrodes by inadvertently being recognized as hydrogen ions and thus the pH values measured are erroneously lower than actual. This may have happened in this case because the available alkalinity values were reasonably high at greater than 8% calcium hydroxide and the chloride ion content was also high at 2000 to 12,500 mg/kg. The high chloride ion content is associated with high sodium ion content in the seawater that also penetrated into the mortar lining with the chloride ions. Superficial corrosion was found on the steel cylinder indicating that the chloride content of the sea water at 30,000 mg/l did not substantially depassivate the steel. The high level of hydroxide ions at the steel surface as well as the slow diffusion of oxygen through the mortar lining helped to minimize the amount of corrosion found on the cylinder when compared to the substantial amount of corrosion found on the bare blind steel flange attached to the end of the pipe.

**Effect of Lining Absorption on Leaching or Carbonation Rate** – The effect of mortar lining absorption on the leaching or carbonation rate is shown in Figure 4. The black line is the trend line through all of the data points. The dashed line excludes the Tucson data with the high carbon dioxide content. The leaching or carbonation rate increased with increasing mortar lining absorption.

## Summary

1. Portland cement mortar linings have been used on steel water pipelines for more than 150 years to prevent corrosion.
2. Portland cement mortar is the predominant lining system for steel, cast-iron, and ductile-iron water pipelines to prevent corrosion.
3. Portland cement mortar linings are thick, durable, easily repaired, require essentially no steel surface preparation, can be applied in almost all weather conditions, and passivate steel which protects steel from corrosion.
4. Portland cement mortar linings benefit from exposure to and penetration of water from the surrounding environment.
5. Portland cement mortar linings are not leached or carbonated in most hard waters. They can expect an indefinitely long service life and 100 years is a reasonable expectation.

6. Portland cement linings are leached to a greater extent as the water softness increases. They are expected to have decades of service with 50 to 100 years being reasonably attainable with minimal, if any, corrosion of the steel cylinder.



(Leaching or carbonation rate detection limit is 1.6 mils/yr. Values less than 1.6 mils/yr are plotted to indicate very low, if any, leaching or carbonation)

**Figure 4. Effect of mortar absorption on leaching or carbonation.**

### References

American Water Works Association (2008). AWWA C104-08 Standard, “Cement-Mortar Lining for Ductile-Iron Pipe and Fittings.” Denver, CO.

American Water Works Association (2007). AWWA C205-12 Standard, “Cement-Mortar Protective Lining and Coating for Steel Water Pipe – 4-in. (100 mm) and Larger – Shop Applied.” Denver, CO.

American Water Works Association (2006). AWWA C303-08 Standard, “Concrete Pressure Pipe, Bar-Wrapped, Steel Cylinder Type.” Denver, CO.

Bardakjian, H. (1995). “Quality Enhancements of Cement-Mortar Coatings.” Advances in Underground Pipeline Engineering, ASCE, New York, NY, 734-744.

Bardakjian, H. and Hausmann, D. A. (2007). “Corrosion Protection of Large Diameter Welded Steel Pipelines with Cement Mortar Coatings.” Pipelines 2007: Advances & Experiences with Trenchless Pipeline Projects, ASCE, Reston, VA, 1-10.

Rosa, E. B., McCollum, B., and Peters, O. S. (1913). “Electrolysis in Concrete – No. 18.” U. S. Bureau of Standards, Washington, DC.