External Protection of Concrete Cylinder Pipe
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Types of Concrete Cylinder Pipe ................................................. 1

- Prestressed Concrete Embedded-Cylinder Pipe ......................... 1
- Prestressed Concrete Lined-Cylinder Pipe ............................ 1
- Bar-Wrapped Concrete Cylinder Pipe .................................. 1
- Reinforced Concrete Cylinder Pipe .................................... 1

Corrosion Resistance of Concrete Cylinder Pipe ....................... 1

Protection of Concrete Cylinder Pipe in Adverse Environments ........... 4

- High-chloride environments ................................................. 4
- Stray current interference .................................................. 4
- High sulfate environments ................................................. 5
- Severe acid conditions ..................................................... 5
- Long term atmospheric exposure ........................................ 6
- Connections to other pipelines ............................................ 6

Bonding .................................................................................. 6

Monitoring ............................................................................. 6

Cathodic Protection .................................................................. 9

Glossary of Corrosion Terms ................................................... 11

References ............................................................................... 12
Concrete cylinder pipe has consistently demonstrated longevity and reliability when properly installed in most natural environments. That is attributable to the inherent protection provided by the high pH of portland cement-rich mortar, concrete and slurry which passivate the embedded steel components.

This manual has been developed by the American Concrete Pressure Pipe Association to assist the specifier or owner of a new pipeline by providing guidelines for the supplemental protection of concrete cylinder pipe if it is to be installed in adverse environments.

While it is the belief of the Association that this material represents good practice, the manual should be used as a reference guideline to help readers evaluate their own requirements and specifications. This publication is provided with the understanding that the publisher is not engaged in rendering engineering or other professional services. This manual should not be considered an acceptable substitute for case-specific technical advice. If engineering or other expert assistance is required, the services of a competent professional person should be sought.

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Concrete cylinder pipe is a general designation given to pipe manufactured with a watertight steel cylinder and reinforcing or prestressing wire embedded in a portland cement-rich concrete or mortar. The four types of concrete cylinder pipe most commonly produced in the United States and Canada are:

- Prestressed Concrete Embedded-Cylinder Pipe. AWWA C301. (Figure 1)
- Prestressed Concrete Lined-Cylinder Pipe. AWWA C301. (Figure 2)
- Bar-Wrapped Concrete Cylinder Pipe. AWWA C303. (Figure 3)
- Reinforced Concrete Cylinder Pipe. AWWA C300. (Figure 4)

Prestressed Concrete Embedded-Cylinder Pipe is constructed with steel bell and spigot joint rings welded to opposite ends of a steel cylinder which is embedded in concrete. The core assembly is helically wrapped with high tensile strength prestressing wire which is then encased in a cement-rich mortar coating. A slurry coating of portland cement is applied while wrapping the core with prestressing wire, and again while applying the mortar coating. Field installation results in a watertight joint by compressing the rubber gasket between the bell and the spigot sections.

Prestressed Concrete Lined-Cylinder Pipe is constructed with steel bell and spigot joint rings welded to opposite ends of a steel cylinder which is lined on the inside with concrete. The core assembly is helically wrapped with high tensile prestressing wire which is then encased in a cement-rich mortar coating. A slurry coating of portland cement is applied while wrapping the core with prestressing wire, and again while applying the mortar coating. Field installation results in a watertight joint.

Bar-Wrapped Concrete Cylinder Pipe is constructed with steel bell and spigot joint rings welded to opposite ends of a steel cylinder. A centrifugally cast mortar or concrete lining is placed inside the cylinder. The assembly is then helically wrapped with mild steel rod and an exterior cement mortar coating is applied. A slurry coating of portland cement is applied while wrapping the assembly with steel rod and again while applying the mortar coating.

Reinforced Concrete Cylinder Pipe is constructed with steel bell and spigot rings welded to opposite ends of a steel cylinder. The steel cylinder and one or more reinforcing cages are cast into a concrete wall.

Concrete cylinder pipe provides trouble-free service when properly installed in most environmental conditions. Corrosion protection is provided to the embedded steel elements of the pipe by the high alkalinity of hydrated portland cement, which has a pH in the range of 12.5 to 13.5. At that pH a passivating oxide film forms and is maintained on embedded steel surfaces, which precludes the possibility of electrochemical corrosion, except in adverse environments.

In the absence of an external impressed voltage, passivated steel in concrete has a potential ranging approximately from 0 to -200mV to a copper-copper sulfate reference electrode (CSE). That potential is 300 to 500 mV more noble than the potential of bare or organically coated steel. Any significant shift in the potential of steel in concrete away from the passive range is an indication of possible corrosion activity or stray current interference. The unique potential of passivated steel in concrete makes possible pipeline potential monitoring of concrete cylinder pipelines to determine corrosion activity. In order to do this monitoring, the pipeline must be electrically continuous. (see Bonding and Monitoring).
Figure 1 - Prestressed Concrete Embedded-Cylinder Pipe. Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.

Figure 2 - Prestressed Concrete Lined-Cylinder Pipe. Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.
Figure 3 - Bar-Wrapped Concrete Cylinder Pipe. Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.

Figure 4 - Reinforced Concrete Cylinder Pipe. Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.
PROTECTION OF CONCRETE CYLINDER PIPE IN ADVERSE ENVIRONMENTS

In most installation environments, no supplemental corrosion protection is required for concrete cylinder pipe. Adverse environmental conditions, where precautionary measures may be necessary to ensure pipeline integrity, are:

- High-chloride environments
- Stray-current interference
- High-sulfate environments
- Severe acid conditions
- Long term atmospheric exposure

Soil resistivity can give an indication that high concentrations of chloride, sulfate, or other ions may be present. Because it is easier to measure soil resistivity than soil chemistry, it is recommended that a soil resistivity survey be performed along the pipeline right-of-way to locate potentially aggressive conditions. Where soil resistivity is less than 1,500 ohm-cm, soil chemistry should be analyzed.

HIGH-CHLORIDE ENVIRONMENTS

In order to initiate corrosion, a sufficiently high concentration of chloride ions, in combination with oxygen at the steel surface, is required to disrupt the passivation of steel embedded in concrete or mortar. However, the amount of corrosion will be limited unless the oxygen at the steel surface can be replenished.

For example, in continuously submerged pipelines, the embedded steel in concrete cylinder pipe does not experience damaging corrosion, even in seawater which contains approximately 20,000 ppm chloride ion, due to the extremely low rate of oxygen diffusion through the saturated mortar coating. As a result, supplemental protection over the mortar coating is not required for continuously submerged concrete cylinder pipe. However, a protective coating system should be applied to the exposed portions of the steel joint rings unless they will be encased in portland cement mortar or grout.

Concrete cylinder pipe, buried in soils with significant water soluble chloride concentrations must be evaluated differently than pipe continuously submerged in fresh water or seawater. Where pipe is to be buried in soils with resistivity readings below 1500 ohm-cm and the water soluble chloride content exceeds 400 ppm at those same locations, one of the following protective measures should be used:

- A moisture barrier should be used to protect the exterior surfaces;
- Silica fume in an amount equal to 8 to 10 percent of the cement weight or a corrosion inhibitor should be included in the exterior mortar or concrete; or
- Cathodic protection should be installed if monitoring of the pipeline detects the onset of corrosion.

STRAY CURRENT INTERFERENCE

Stray current interference from nearby sources of direct current, such as impressed-current cathodic protection systems and electric railway or subway systems, may be picked up and discharged by buried metallic pipelines. An example of interference from an impressed-current cathodic protection system is shown in Figure 5. If stray current discharges from an organically coated steel pipeline, the discharge will be at pinholes or other flaws in the coating resulting in corrosion pitting and coating delamination at those locations. If stray current discharges from steel encased in concrete or mortar, it will be distributed over larger surface areas and it will consume excess alkalinity before corroding the steel. Due to those mitigating factors, concrete cylinder pipelines can tolerate stray current interference without the initiation of corrosion for a longer time than organically coated steel pipe. When stray current interference is anticipated or known to exist, one of the following measures should be considered for concrete cylinder pipe:

- Eliminate the source of the stray current if possible.
• Apply a supplemental coating with dielectric properties to the pipe exterior to increase the pipes electrical resistance.

• Provide electrical continuity bonding and monitor the pipeline after installation to determine if stray current is being picked up or discharged. If stray current is picked up, provide the means to safely discharge it.

HIGH SULFATE ENVIRONMENTS

Soils with high concentrations of sodium, magnesium, or calcium sulfates are frequently referred to as alkali soils. These soils can chemically attack concrete structures, but such attack is generally limited to partially buried structures where capillary action and surface evaporation can build up high sulfate concentrations in the concrete or mortar. Completely buried concrete pipelines are not normally subject to sulfate build up. Also, the high cement contents typical of the exterior mortar coating or concrete on concrete cylinder pipe (6 to 10 sacks per cubic yard) have been shown to significantly increase sulfate resistance. Also, a sufficiently low permeability of the placed concrete or mortar has been shown to drastically reduce sulfate attack, such that even high C₃A cements can be used to make concretes or mortars with good sulfate resistance. As a result, sulfate attack on completely buried concrete pipelines is extremely rare. However, exposed or partially exposed concrete pipelines in or on high sulfate soils require protective measures. In these cases, when the water soluble sulfate content of the soil is 2000 ppm or less, standard Type II portland cement should be used. If the soil contains more than 2000 ppm water soluble sulfates, a portland cement with a C₃A content of 5 percent or less or silica fume in an amount equal to 8 to 10 percent of the cement weight should be used. Instead of a special cement or the addition of silica fume, a barrier coating can be used to isolate the pipe exterior from the sulfates.

SEVERE ACID CONDITIONS

Chemical attack of the exterior of concrete pressure pipe in acid soils is rare and usually limited to unnatural conditions such as mine wastes, acid spills or industrial dumps. Such conditions often involve mineral acids, such as sulfuric acids, with very low pH and high total acidity values.

In poorly drained soils, any acid groundwater in contact with the pipe exterior is neutralized by the alkalinity of the mortar or concrete and is slow to be replaced. Therefore, in soils such as fine grained silts or clay, where replenishment is greatly reduced by the imperviousness of the soil, supplemental protection against acid conditions is not normally necessary. If acidic soils are granular, replenishment of acidity at the pipe surface is more easily accomplished.

Guidelines for evaluating the aggressiveness of acid soils and the need for supplemental protection are as follows:

1. In granular soils, when pH measured on the soil sample is below 5, the total acidity should be determined. If the total acidity exceeds 25 meq/
100 gm of dry soil, one of the following precautions should be used:

- Backfill in the pipe zone with consolidated clay material;
- Backfill the pipe zone with calcareous material;
- Install an acid resistant membrane on or around the pipe; or
- Add silica fume in an amount equal to 8 to 10 percent of the cement weight to the mortar coating.

2. Where soil pH is below 4, the pipe should be installed in an acid resistant membrane or in an envelope of nonaggressive consolidated clay.

**LONG TERM ATMOSPHERIC EXPOSURE**

Pipe installed above ground is subjected to a different environment than buried pipe. Above ground lines will be exposed to large temperature fluctuations, wetting and drying cycles, atmospheric carbonation and possibly freezing and thawing cycles, which over a long period of time can detrimentally affect the protective properties of the exterior concrete or mortar coating. For such installations, a light colored barrier coating over the pipe exterior may be used initially and periodically renewed, if deemed necessary to maintain the integrity of the underlying concrete or mortar coating.

**CONNECTIONS TO OTHER PIPELINES**

Because the potential of steel encased in concrete or mortar is 300 to 500 mV less negative than bare or organically coated iron or steel, when a connection is made between a concrete cylinder pipe and bare or organically coated iron or steel pipe, the concrete pipe may be protected by sacrificial corrosion of the ferrous pipe. In most cases, the problem is inconsequential. However, if the problem is to be completely eliminated, an insulating connection should be used in joining the concrete pipe to the ferrous pipe or the ferrous pipe should be encased in concrete or mortar to bring both pipe materials to the same potential.

**MONITORING**

It is good engineering practice to periodically monitor the electrical potential of all buried pipelines having metallic components to determine if electrochemical conditions exist that could detrimentally affect the performance of the pipeline. By periodically monitoring the pipeline, corrosion activity can be detected and remedial action taken before significant damage occurs.

Potentials reflect electrochemical reactions occurring on metal surfaces in the pipeline and are measured against a standard reference electrode. A copper-copper sulfate electrode (CSE) is commonly used for pipeline surveys. Potentials should be measured at close intervals equally spaced along the pipeline to avoid missing unusual conditions. Spacings of three to ten feet are commonly used.
When bonding inside the pipe as shown in Diagrams A and B, recesses in the lining of the concrete core are chipped as required after pipe field assembly or are blocked out during pipe manufacture. All recesses are then filled with cement mortar.

When bonding from the outside as shown in Diagram C, the bonding cable is welded to the angle-shaped clips and encased in the exterior joint grout.

Figure 6 - Typical bonded joints for AWWA C301 embedded cylinder pipe. Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.
The bonding methods shown provide electrical conductivity across the joint and accommodate relative movement due to pipeline settlement. To provide access for welding the bonds, as shown in Diagrams A and B, recesses are chipped in the mortar coating as required after field assembly. Separate bonding is not required when joints are field welded.

**Figure 7 - Typical bonded joints for AWWA C301 lined-cylinder pipe or AWWA C303 pipe.** Reprinted from Concrete Pressure Pipe, M9, by permission. Copyright © 1995, American Water Works Association.
In the absence of stray currents or cathodic protection, pipeline potentials less negative than -200 mV (CSE) indicate the pipeline is free of damaging corrosion. Potentials more negative than -350 mV, large variations in potentials along the pipeline, and long term trends towards more negative potentials are all indications of corrosion activity.

A decision to periodically monitor pipelines requires that initial design and construction should include provisions that make all metallic components of the pipeline electrically continuous.

A decision to monitor a pipeline also requires a commitment by the owner to establish a periodic monitoring program. If a line is not monitored, an owner is unlikely to realize the full benefits from the added initial cost of making a pipeline electrically continuous. In addition, there is a possibility that corrosion related problems on a bonded pipeline, if they occur, may progress at a rate faster than on an un-bonded pipeline.

There are some limitations in monitoring for corrosion activity on any pipeline:

- The soil surface must be adequately moist to obtain meaningful readings.
- Monitoring potentials cannot be taken through either concrete or asphalt pavement. When readings are to be taken in paved areas, it is necessary to drill small holes through the pavement to permit the reference electrode to be in contact with moist soil or to place the reference cell on unpaved soil near the pipeline.
- Stray currents or impressed direct currents affect potential measurements. Currents collecting on the pipeline make measured potentials more negative; discharging currents make potentials more positive.
- Potentials of connected organically coated steel pipelines are more negative than potentials of concrete or mortar coated steel and will therefore appear as corrosion sites on a concrete pipeline.
- Knowledge of the existence and location of other underground structures (tanks, pipelines, etc.) in the vicinity and appurtenances (valves, branch outlets, etc.) on the pipeline being monitored are necessary for proper interpretation of the readings.

An effective monitoring program starts by taking an initial set of readings, about one year after the pipeline is installed. Time intervals between subsequent surveys are usually established after evaluating the results of prior surveys. Changes in the vicinity of the pipeline such as new construction, implementation of cathodic protection on other structures, or adjustments in existing cathodic protection systems on other structures may necessitate surveys sooner than otherwise scheduled. Significant changes in the readings at a particular location over time or significant differences in the readings at one location compared with readings at adjacent or nearby locations, may be indicative of corrosion or stray current interference. A qualified corrosion engineer, experienced in the protection of concrete pressure pipe, is important not only for conducting monitoring surveys but also for interpreting the readings.

**CATHODIC PROTECTION**

Concrete cylinder pipe rarely requires cathodic protection because of the corrosion protection provided by the alkalinity in the portland cement concrete or mortar coating. Cathodic protection should not be applied indiscriminately. Should monitoring or other pipeline investigation indicate the likelihood of corrosion in a concrete cylinder pipeline, the area in question should be excavated to permit visual examination of the pipe if at all possible. Frequently, monitoring potentials indicative of corrosion are caused by corrosion of appurtenances in the pipeline such as valves or branch lines connected to the concrete cylinder pipe. Should corrosion be found on the concrete pipe, repair or replacement of the affected pieces should be a first consideration. If this is not possible, cathodic protection can be applied to the affected portion of the pipeline to mitigate further corrosion.

When cathodically protecting prestressed concrete cylinder pipe, it is very important that the maximum current-interrupted potential not be more negative than -1,000 mV to a copper/copper sulfate reference cell to avoid evolution of hydrogen and possible embrittlement of prestressing wire. A 100 mV shift in potential has been used to cathodically protect steel in concrete, even if corroding, concrete cylinder pipelines still have the vast majority of the steel surfaces passivated by mortar or concrete. As a result, the current density requirements to provide cathodic protection are far less than would be needed if all steel surfaces were bare. Current
density requirements for concrete cylinder pipe to achieve the minimum 100 mV shift can be expected to fall within the range of 10 to 100 microamps per square foot of pipe outside surface area. If the concrete cylinder pipe has an exterior dielectric membrane or barrier coating, the 100mV shift with current densities of less than 10 microamps per square foot can be expected.

For the limited conditions where cathodic protection of concrete cylinder pipe is required, use of sacrificial galvanic anodes is usually more economical. Such a system has other advantages over an impressed current system:

- Galvanic anodes are unlikely to cause stray current interference problems on nearby structures;
- Galvanic anodes are unlikely to cause hydrogen evolution; and
- They require less frequent monitoring, maintenance and adjustment.

Regardless of the system used, cathodic protection should be designed, operated and monitored by qualified technical personnel.
GLOSSARY OF CORROSION TERMS

THE DEFINITIONS OF THE CORROSION TERMS LISTED BELOW ARE CONSISTENT WITH THEIR USE IN THIS DOCUMENT

ANODE: The electrode of an electrochemical cell in which the loss of electrons (and generally loss of metal ions) occurs. (Refer to Glossary: Electrochemical Cell).

BONDING: The process of making a reach of buried pipeline electrically continuous by tying together all steel elements of an individual pipe and providing low resistance field connections across each pipe joint.

CALCAREOUS: Material containing compounds of calcium; particularly calcium carbonate. Limestone is an example of a calcareous material.

CARBONATION: The chemical reaction of calcium hydroxide (in cement) with carbon dioxide. The primary product of this reaction is calcium carbonate.

CATHODE: The electrode of an electrochemical cell in which the gain of electrons occurs. Loss of metal does not generally occur at the cathode. (Refer to Glossary: Electrochemical Cell).

CATHODIC PROTECTION: The mitigation of corrosion by the application of an external potential opposite to the direction of the corrosion activity.

COPPER - COPPER SULFATE ELECTRODE (CSE): A reference electrode used (in conjunction with a high impedance voltmeter) to determine pipe to soil potentials in a buried pipeline.

CURRENT-INTERRUPTED POTENTIAL: The measured potential of the buried pipeline when the cathodic protection system is deactivated.

ELECTROCHEMICAL CELL: An electrolytic cell containing four principal components: an anode, a cathode, an electrolyte, and a current path. In an electrochemical cell, direct current will flow from the anode to the cathode due to a potential difference between the two electrodes.

MONITORING: The process of determining corrosion activity in a buried pipeline through periodic electrical surveys.

pH: A measure of the hydrogen ion activity or intensity in an electrolyte. The lower the value of pH the more acidic the medium will be.

PASSIVATION: The reduction of the anodic reaction rate for steel embedded in portland cement mortar due to chemical reactions occurring on the metallic surface which create counter or polarization potentials.

PIPELINE POTENTIAL: The electrical potential between the metallic components of a pipeline and a reference electrode, the determination of which is made by monitoring. Experienced corrosion engineers can generally determine the corrosion activity of the buried pipeline from these measurements.

POTENTIAL: The electrical state of material, the units being in volts (V) or more commonly mV (one thousandth of a volt).

RESISTANCE: The tendency of an electrical circuit to retard the flow of current. Resistance is measured in ohms.

SOIL RESISTIVITY: A measure of the effective resistance of soil to the conduction of electrical current over a unit distance. It is measured in ohm-centimeters.

STRAY CURRENT INTERFERENCE: The unintentional collection or discharge of current in a metallic (or mortar encased) pipeline due to its proximity to an external source of direct current. Generally loss of metal occurs at the discharge (anodic) area while no loss of metal is experienced at the collection (cathodic) area.
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