

**CONDUCTING PRECAST CONCRETE CYLINDER PIPE
CONDITION ASSESSMENT
BY
MATCHING CORROSION DAMAGE MECHANISMS TO
DIAGNOSTIC METHODS**

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Abstract

Precast concrete cylinder pipe (PCCP) has been widely used successfully for both water transmission and wastewater force mains for many decades. In the case of water conveyance, the majority of failures occur due to soil side deterioration. This includes chloride intrusion and low pH soils and ground water promoting corrosion of the prestressed wires. High sulfate bearing ground waters can also cause expansive degradation of the cement mortar coating exposing the prestressed wires to corrosive conditions. Internal corrosion rarely results in PCCP failure in potable water conveyance.

In force mains, the same soil side damage mechanisms experienced by water transmission pipelines are commonplace. But, force mains also fail due to internal biogenic sulfide corrosion where air pockets are present.

Under both external and internal corrosion scenarios, PCCP manufactured with Class IV (and to a lesser extent with Class III) prestressed wire can be susceptible to rupture associated with hydrogen embrittlement and dynamic strain aging or DSA. Understanding the background design data on the pipe can highlight the likelihood of this propensity.

Diagnostic technologies for acoustically identifying wire breaks and electromagnetic tools for locating wire breaks are available and useful, but very expensive and intrusive to operations. These indirect assessment tools are often not necessary.

Experience has shown that direct assessment of soil corrosivity and pipe integrity based on known damage mechanisms provides sufficient data to determine pipeline conditions and ascertain likelihood of failure.

This paper presents a protocol for direct pipeline condition assessment that establishes prioritized risk and rehabilitation or replacement needs for PCCP pipelines. Case histories describing this condition assessment approach are included.

Keywords:

PRECAST CONCRETE CYLINDER PIPE (PCCP); CEMENT MORTAR COATING; DYNAMIC STRAIN AGING; HYDROGEN EMBRITTLEMENT

Introduction

The major damage mechanisms for Precast Concrete Cylinder Pipe (PCCP) are well-known for both water transmission mains and wastewater force mains.

Soil side corrosion is the most prevalent cause of PCCP failures. This is caused by chloride intrusion through the cement mortar coating to the prestressed wires. Soil side corrosion can be the result of exposure to acidic groundwater and soils. In these cases, the cement mortar coating is broken down by acidic attack and the wires are subjected to the corrosive electrolyte. High sulfides bearing ground waters can also promote cement mortar coating degradation. Sulfate reactions cause expansive deterioration of the cement mortar exposing the prestressed wires to corrosive soil conditions.¹

Manufacturing related problems have also been responsible for many PCCP main failures over the past 50 years.

Manufacturing problems due to the use of very high tensile strength wires for prestressing have caused the failures. This failure mechanism is called dynamic strain aging (DSA) and is associated with the propensity of these wires to break and fail due to hydrogen embrittlement. This failure mechanism typically occurs in the susceptible prestressing wires once deterioration of the cement mortar coating has degraded or been damaged and wire corrosion can proceed. In other words, once corrosion occurs within these susceptible wires, hydrogen enters the steel and the embrittlement mechanism develops. As this progresses, wires break. Once a sufficient number of wire breaks occur in a given distance, the pipe fails (usually catastrophically). These failures are most commonly initiated by external corrosion. Class IV wire made solely by Interpace Corporation in Solon, Ohio in the early 1970's through the early 1980's has shown the greatest frequency of these types of failures. This has occurred with both lined cylinder pipe (LCP) and embedded cylinder pipe (ECP). However, Class III wire (somewhat lower in tensile strength than Class IV wire) has also exhibited similar embrittlement related failures in mostly LCP. PCCP made with Class III wire was also manufactured by PCCP manufacturers other than Interpace.²

Another important historical fact is that there have been more PCCP failures associated with 8 gauge wire than with 6 gauge wire. And most of the pipe made between 1964 and 1984 was made using 8 gauge wire.³

It is very important to note that hydrogen embrittlement of prestressed wires, even those produced under DSA conditions, does not occur without a source of hydrogen present. Corrosion of the wires is generally the source of the hydrogen. Hence if the cement mortar coating is unattacked and no internally driven corrosion causes wire corrosion, hydrogen embrittlement of the prestressed wires does not occur. This is why there are thousands of miles of PCCP made with Class IV and Class III wire susceptible to DSA that have not failed over many decades of service.

As discussed above, corrosion damage is caused due to adverse exposure conditions. This includes both internal and external corrosion. Internal corrosion of PCCP in wastewater typically involves biogenic sulfide corrosion damage. In force mains, this means there is a headspace or air pocket in the pipe within which sulfur oxidizing bacteria can metabolize H₂S to form sulfuric acid. In a non-prestressed pipe, the concrete on the interior face of the crown is normally in a tension zone, and therefore essentially serves only as corrosion protection for reinforcing. However, in a prestressed pipe, the concrete is placed into compression and contributes to the strength of the pipe. Therefore, loss of wall thickness through dissolution of the cement paste potentially reduces the structural capacity of the pipe to support load. Internal corrosion also ultimately causes prestressed wires to fail.

Operation issues can also cause or contribute to PCCP failures. Scenarios under which the mains are over-pressurized or when significant and repeated transient pressure events occur, the pipes can fail due to excessive stresses. More often than not this involves prestressed wires which have corroded to some extent prior to the hydraulic events.

Additionally, stray current driven corrosion of prestressed wires in PCCP can develop from nearby impressed current cathodic protection systems or when the PCCP itself is over protected by impressed current cathodic protection current.

Construction related quality problems can also result in PCCP corrosion related failures. A classic case involves poor external joint grouting leaving the bell and spigot rings exposed to corrosive groundwater and soil.

Performing condition assessment on aged PCCP mains should first take into consideration the likely damage mechanisms which have caused or can cause pipeline failure.

The use of acoustic and electromagnetic detection technologies for identifying wire breaks and locating wire breaks in PCCP are proven and useful diagnostic tools. However, these technologies are often over-used when direct assessment of soil corrosivity, review of the hydraulic profile (force mains), evaluation of prior failures, and physical inspection of the pipe externally can identify deterioration and establish risk of future pipeline failure. These assessments should be performed first to determine if the risk is sufficiently high to justify the high cost of utilizing the acoustic or electromagnetic assessment tools.

This logical technical approach to PCCP main condition assessment matches diagnostics to the expected damage mechanisms.

Recommended Protocol for PCCP Condition Assessment

Based on the likely damage mechanisms, the protocols set forth below are recommended for condition assessment of aged PCCP mains.

External Corrosion Damage

A. Background Design Data

Identify the design information, if available, for the pipe. This should include review of the specifications from the pipe manufacturer and the laying schedules. From this information, the prestressed wire tensile strength (wire type, i.e. Class II, III, or IV, etc.), the prestressed wire gauge, the bell and spigot joint ring thickness, the number of wire wraps per ft., the concrete core thickness, and the cement mortar coating thickness can be ascertained.

This information will help you evaluate the risk of DSA and hydrogen embrittlement propensity for the prestressed wires. It will also identify the concrete core layer (inner and outer dependent on LCP or ECP) thicknesses which are important especially for biogenic sulfide corrosion of force mains. If the prestressed wire Class is I or II, the likelihood of DSA problems is very low. Conversely if Class III or IV wire was used in the pipe, this risk is much higher for DSA issues.

B. Review Past Records of Pipe Failures (Leaks)

If prior failures have occurred, were the failures shown to be caused by external driven corrosion of the prestressed wires or internally driven corrosion? The answers can likely be found in prior failure analysis reports or by examining the failed pipe sections retained. The answers to these questions are critical to risk assessment.

Also, is there a pattern to prior pipe failures? Were the failures explosive ruptures or longitudinal cracks followed by leakage? Were the leaks all in close proximity to the discharge side of a pump station? This

could mean transient pressure conditions have contributed to the prior failures. And if the failures were ruptures, it is likely that prestressed wire breaks caused by external corrosion of the prestressed wires explain the failure mode.

If there were no prior leaks or failures, proceed to Steps C. or D. in this protocol as delineated below.

C. Review Force Main Hydraulic Profile (Internal Corrosion Damage)

For force mains with or without prior failures or leaks, review the hydraulic profile. Look for high points such as air release valve (ARV) locations where air pockets (gas pockets) can form in the crown area of the pipe. This is where biogenic sulfide corrosion can occur and attack the inner concrete core of the pipe followed by cylinder and outer concrete and/or prestressing wire corrosion. If no leaks or failures have occurred previously, check to be certain the ARVs along the force main are operating properly and are well-maintained. If there have been prior failures, determine if the failures occur at or near ARV or other high points in the hydraulic profile. If so, it is highly likely that the failures were associated with internal biogenic sulfide corrosion. Refer to prior failure analysis reports for information on whether corrosion was internal or external. When this is the case, it is highly probable that the limits of the pipe degradation are limited to some finite distance on either side of the failure at the high point.

If the background data indicates the failure was due to internal corrosion, the installation of a tapping sleeve at a test pit and core sampling of the pipe is recommended. This permits examination of the cement mortar coating, the prestressed wires, the outer concrete core, the steel cylinder, and the inner concrete core to discern the pipe condition. This method of examination taken at or near a high point in the hydraulic profile also provides identification of internal crown acidic attack in the pipe.

D. Conduct Soils Corrosivity Sampling and Testing

For force mains where external (soil side) corrosion damage was evident from past records or for water mains, surveil the alignment of the pipelines to identify areas conducive to soil-soil side corrosion. Look for wetlands (marshy areas), areas near the ocean or brackish bodies of water, areas near water courses such as rivers or streams, run-off areas in roadways where the accumulation of deicing salts is expected to be high, or prior industrial sites or agricultural run-off areas. Have soil samples obtained at such areas and at areas not conducive to soil corrosion (well drained benign areas). Soil sampling to be taken at pipe burial depth. Test those soil samples for pH, chlorides, sulfates, water content, and resistivity. This data can be used to characterize the likelihood of corrosion to the cement mortar coating or to exposed prestressed wires or joint rings in the pipe.

It is also very important to have the geotechnical resource determine the depth of the water table or ground water below grade at the soil sampling locations. The presence of ground water on the external pipe surfaces especially if it fluctuates is a major contributor to pipeline corrosion assuming the water and soils are corrosive. Fluctuating groundwater levels also mean higher dissolved oxygen levels which enhance metallic corrosion. This soil testing directly addresses the likely soil side corrosion mechanisms of chlorides, low pH, or high sulfates.

E. Perform External Pipe Condition Examination at Test Pits

Based on the soils testing data obtained, perform test pit excavations at a few locations where corrosive soil conditions were identified. If past failures have occurred, consider performing test pits near the prior failures as well as at areas of low soil corrosivity. Once exposed, examine the condition of the cement mortar coating. Hammer sounding it to determine its integrity. Also, scrape and chip the mortar coating to various depths down to the prestressed wires and perform pH measurements on the cement mortar at

each successive depth. This is done to determine if alkaline protection of the wires remains present. The cement mortar coating removal must be performed very carefully.

Careful cement mortar coating removal in small areas can also be performed so that the wires can be examined for evidence of corrosion damage. The test pits should include at least a few joint locations such that the quality of the external joint grouting performed when the pipe was installed can be evaluated. Lack of grout or improper diaper placement leaving non-grouted gaps in the bell-spigot joints can cause joint ring corrosion. This corrosion can cause concrete core cracking and progress to prestressed wire corrosion over time.

These physical examinations of the pipe will identify soil side attack problems and help project teams assess the risk of future pipeline failures.

F. Other Considerations

Other considerations include checking to see if the pipeline is cathodically protected with impressed current or sacrificial anode cathodic protection. If the pipe is cathodically protected, pipe to soil potentials and anode current output measurements should be taken at test stations. If the pipe is protected with an impressed current system, measurements should be taken at the rectifiers to be certain the system is not shifting the potential of the wires too far electronegatively. This can cause hydrogen embrittlement of the pipe's prestressed wires resulting in pipe failure.

Check to see if all prior failures occurred near a pump station discharge. If no failures occurred elsewhere on the alignment, it may be that the pipe's problems are more related to transient overpressure conditions and not corrosion.

Check to be certain prior failures are not related to an adjacent or crossing pipeline that is cathodically protected with an impressed current system. Stray current induced corrosion can cause prestressed wire failures along PCCP mains.

Assessing Risk of Failure – When to DeDeploy Internal Testing

Here are some practical guidelines for assessing risk of future PCCP failure and path forward recommendations:

1. If there have been past failures at multiple widespread locations along the alignment and initial assessment reveals prestressed wire corrosion occurred from external soils, consider the use of electromagnetic examination (internal) to identify areas of frequent wire breaks. These areas will be prioritized for either retrofit or replacement.
2. If no prior failures were shown in the main, but soil corrosivity revealed corrosive conditions and pipe examination exhibited degraded cement mortar coating and/or wire corrosion, proceed to having electromagnetic examination inspection performed internally. This is more urgent if the pipe was made with Class III or IV prestressed wire. If conversely the soils were found to be non-corrosive to PCCP and pipe examination revealed good pipe conditions, there is no need to perform internal evaluations or surveys.
3. If past failures were shown to be related to joint grouting, perform soils corrosivity testing and excavation and inspect joints at several locations to determine pipe joint conditions at more locations to discern if this problem is widespread or isolated to a few joints. In such cases, internal electromagnetic surveys are not likely warranted. Rather, further external evaluation of joints and pipe conditions by excavation should be conducted.