Numbers Don't Lie, PCCP Performance and Deterioration Based on a Statistical Review of a Decade of Condition Assessment Data

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ABSTRACT

Since the late 1990s there have been numerous inspection and monitoring projects focused on identifying and quantifying wire break damage in PCCP water and wastewater pressure mains. The pressing need to identify and manage deterioration of PCCP has resulted in the rapid development of a small but highly focused niche industry of condition assessment of PCCP mains. During this time, there have been various theories and postulations regarding the performance and deterioration of PCCP mains. This paper statistically reviews data from more than 500 miles of electromagnetic inspection and acoustic monitoring that have been performed since 2001 to develop scientifically based conclusions on a variety of topic areas regarding the performance and deterioration of PCCP mains. Topic areas include:

- The mean for percent of damaged pipe sections (percent of damage) are reported. The industry has many views on the performance of PCCP. This paper reports the percent of damage by reviewing the total number of PCCP sections inspected and those that were reported as having wire break damage.

- The percent of damage is further evaluated by the year of manufacture binned according to the various AWWA C301 and C304 versions. This includes an analysis of what is the mean percent of damage for pipe manufactured with Class IV prestressing wire.

- Percent of damage is also compared between embedded cylinder or lined cylinder pipe to determine if one type of design has an improved performance.

- Percent of damage is also compared for water (including raw water) vs. wastewater mains

INTRODUCTION

Prestressed concrete cylinder pipe (PCCP) is often used to construct large diameter pressure pipe for water utilities and force mains for wastewater utilities. These mains are usually of high importance for utilities and unexpected service interruptions from pipeline failures, places a significant burden on the utility and may result in the utility not being able to meet its customer's needs. As a result of the importance of these mains, since the early 2000s, 122 condition assessment projects have been performed involving either electromagnetic inspection or acoustic monitoring. Many theories and industry accepted practices associated with PCCP have been developed and circulated in the water and wastewater industries. A comprehensive review of the database from electromagnetic inspection projects and acoustic monitoring projects is underway to provide scientifically backed information on the performance of PCCP water transmission mains and sewer force mains.

The primary structural component of PCCP is a prestressing wire wrapped, under tension, around the pipe core. Electromagnetic inspection and acoustic monitoring are non-destructive technologies that obtain quantified data on the number of broken prestressing wire wraps and the rate of wire breaks respectively. By reviewing the database associated with these condition assessment projects, observations can be made regarding design parameters associated with various pipeline designs employed.

While distress rates are low for PCCP, it only takes one bad pipe section to generate pipeline failure. Therefore, performing condition assessment and proactive management of important PCCP mains is a sound pipeline management task. A concept of "Assess and Address" is introduced which is a pipeline management alternative to capital replacement projects for aging mains. This method relies on assessing the condition of a pipeline to quantify damage/risk and performing isolated repairs on sections of pipe experiencing advanced deterioration.

DATABASE

Electromagnetic inspection of PCCP has been performed since the late 1990s. A review of the entire database was not performed as part of this study, but a significant portion of the database was reviewed. The review included PCCP inspections from 55 utilities in the United States and Canada. Significant PCCP inspections have been performed in Libya, Mexico, South America, and China, but data from these inspections was excluded so statistically significant conclusions could be made regarding installations in the U.S. and Canada. The review included pipeline with diameters ranging from 16-inches to 162-inches and installation years from 1952 to 2004. The database reviewed included 420 miles of PCCP.

Acoustic Fiber Optic (AFO) monitoring has been used to continuously monitor PCCP to detect the acoustic event associated with a breaking PCCP wire. The technology reports the time and location of wire breaks, but does not report wire breaks prior to installation of the monitoring system. In many cases, AFO systems are installed following inspection and repair of a pipeline so that ongoing pipeline deterioration can be tracked and the pipe can be proactively managed. The database for AFO monitoring includes 167 miles of PCCP pipeline ranging from 36-inches to 102-inches in diameter and installation years from 1958 to 1990. The systems have detected 3445 wire breaks on these pipelines.

PERCENT OF DAMAGE

There are many rumors that circulate in the industry regarding the performance and reliability of PCCP. Manufacturers of the product, state that if installed and managed correctly this pipe material should have an extremely long service life. Review of the database supports this assertion.

The electromagnetic inspection results reviewed in the database covered 118,808 pipe sections or 2.1 million feet of PCCP, or 405 miles (not all 420 miles in database could be compiled due to partial data on some projects). A total of 4,598 pipe sections were reported to have wire break damage, the principal failure mechanism of PCCP. This indicates that only 3.9% of PCCP has electromagnetic signatures consistent with wire break damage. Alternatively, it could be said that 96.1% of pipe sections do not have any damage and are usually considered in "like new" condition.

Review of the AFO database included monitoring data associated with 49,519 pipe sections. Of these, acoustic events associated with wire breaks were reported on 1918 pipe sections. This means that the number of pipe sections with wire break damage reported by AFO is also 3.9%, consistent with the results from electromagnetic inspection. Findings are summarized in Table 1.

This average percent of damage is a significant finding. In many instances utilities are frustrated by multiple failures on a pipeline. It only takes one significant large diameter pipe failure to generate frustration and a lack of confidence in a pipeline. When multiple failures occur, this may lead a utility to replace the pipeline when on average, more than 96% of the pipeline may be in pristine, or like-new, condition. The challenge for utilities is to identify the "weak link" in the pipeline so that the pipe can be proactively managed. If this is performed, large capital replacement projects may be averted, offering significant savings to clients. This concept is referred to as "Assess and Address" in this paper versus capital replacement.

Table 1
Percent of Damaged Pipes as Reported by Electromagnetic Inspection or Acoustic Monitoring

Technology Type	Number of Pipe Sections	Number of Pipe Sections Reported with Wire Break Damage	Percent of Pipe Distressed Sections	Feet Inspected*	Miles Inspected*
Electromagnetic Inspection	118,808	4,598	3.9%	2,138,544	405**
Acoustic Monitoring	49,519	1,918	3.9%	891,342	169

* Based on an assumed average pipe section length of 18 feet.

**Not all 420 miles in database could be compiled due to partial data on some projects.

LEVEL OF DAMAGE

The presence of wire break damage alone does not provide a full picture of a pipeline. The extent of damage or number of broken wire wraps provides a better understanding of a pipe section and what condition it's in. As part of the database review, the extent of damage was binned into different levels of damage. The no wire break damage bin was selected to determine the percent of pipe sections without damage. The next bin (0 to 15 wire breaks) was selected as this typically represents 12-inches or less of damage and does not usually pose a significant risk of near term failure. The remaining bins were selected arbitrarily. The results of this evaluation are summarized in Table 2 and Figure 1.

Of the pipe sections that experience wire break damage 57% of these pipes were reported to have 15 or fewer broken prestressing wire wraps. Although many variables must be considered when making repair decisions, these pipe sections are usually of low risk are not repaired. This further supports the Assess and Address concept mentioned above as usually 98.6% of PCCP mains are of lower risk for failure and can be managed.

It should again be emphasized that although these distress rates are low, it only takes one bad pipe section to generate a significant failure. An AWWA study recently cited that a large diameter pipe failure typically costs a utility between $200,000 and $1,500,000, including ancillary damages. Thus while the distress rates are low, it's important to find deteriorated pipe and implement corrective measures.

Table 2
Level of Wire Break Damage Grouped into Bins*

	No Wire Break Damage	Between 1 and 15 Broken Wire Wraps	Between 16 and 30 Broken Wire Wraps	Between 31 and 75 Broken Wire Wraps	Greater Than 75 Broken Wire Wraps
Total	110,974	2263	816	495	365
Percent	96.6%	2.0%	0.7%	0.4%	0.3%

* Not all 420 miles in database could be compiled due to partial data on some projects.

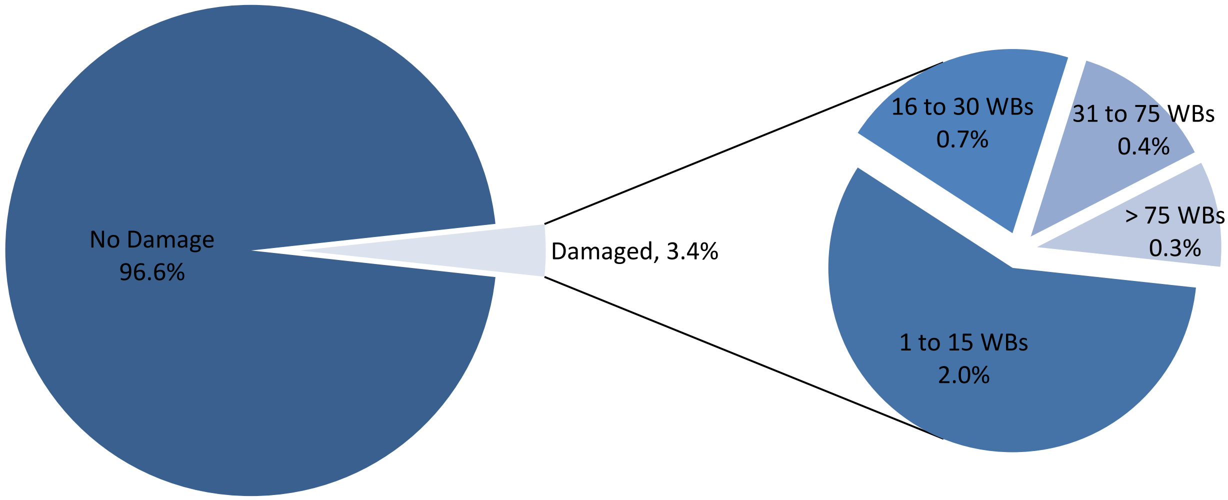

Figure 1- Level of wire break damage grouped into bins

PERCENT OF DAMAGE BY VINTAGE

Over the years, various AWWA standards have been adopted for the design and manufacture of PCCP. As pointed out in the Bell/Romer paper, pipes manufactured from 1972 to 1978 had a high probability of Category 1 or 2 failures. This is likely due to the AWWA standards and installation practices of that time permitting the use of PCCP with Class IV wire and thinner mortar coatings.

The electromagnetic inspection database was reviewed to determine if rates of wire break damage could also be correlated to year. Table 3 shows the results of this review and is also illustrated in Figure 2. Consistent with the Bell/Romer finding, PCCP manufacture from 1972 to 1978 have higher percent of damage than pipe manufactured from other eras. However, not consistent to the Bell/Romer paper, the second highest percent of damage category was pipe manufactured from 1965 to 1967. Another inconsistency with the Bell/Romer paper is that the percent of damage for pipe sections manufactured from 1965 to 1967 is approaching that of pipe sections manufactured between 1972 and 1978 (3.6% compared to 4.5% respectively).

Table 3

Percent of Damaged Pipe According to Various AWWA Standards **

Era	Number of Pipe Sections Inspected	Number of Distressed Pipe Section	Percent of Pipe Sections Distressed	Feet Inspected*	Miles Inspected*
Pre 1955	1,228	2	0.2%	22,104	4
1957 -1963	5,982	24	0.4%	107,676	20
1965-1967	7,409	269	3.6%	133,362	25
1968-1971	11,713	294	2.5%	210,834	40
1972-1978	21,602	966	4.5%	388,836	74
1979-1991	7,348	82	1.1%	132,264	25
Post 1992	356	-	0.0%	6,408	1

* Assumes average pipe section length of 18 feet.

** Not all 420 miles in database could be compiled due to partial data on some projects.

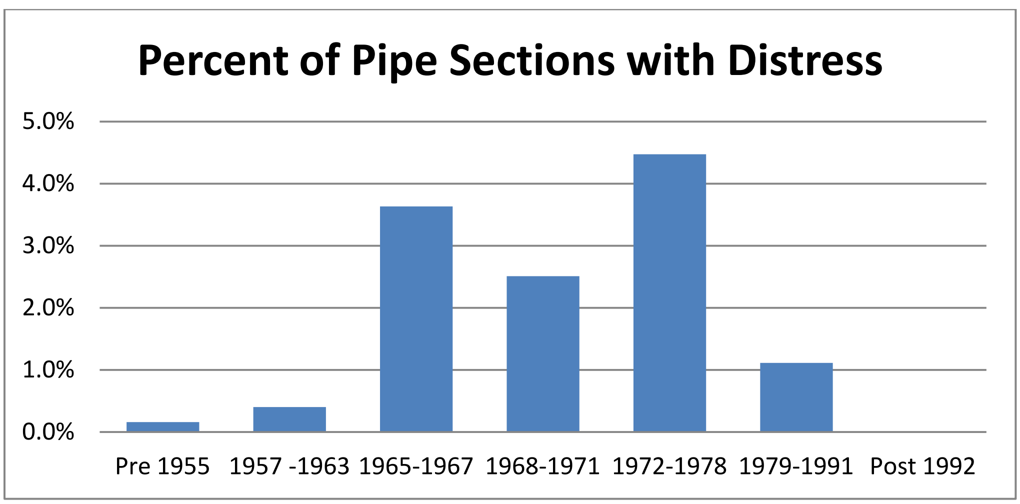

Figure 2- Distress levels by vintage

EMBEDDED VS. LINED CYLINDER PIPE

There are two predominant types of PCCP design in the U.S. and Canada: 1. lined cylinder pipe, where the prestressing wire is wrapped directly on the steel cylinder and 2. embedded steel cylinder where the cylinder is encased (or embedded) in a concrete core and the prestressing wire is wrapped around the concrete core. There has been much debate over the performance record of these two types of pipe. For lined cylinder, it is often stated that since the wire is wrapped on the core and the core is thinner, the pipe is more flexible and will deteriorate faster. By reviewing the database, it is apparent that this is not the case. In fact, the rate of distress for lined cylinder pipe is about half of that for embedded cylinder pipe, 2.1 % vs. 4.1% respectively. This is further summarized in Table 4 and is illustrated in Figure 3.

Table 4
Lined Cylinder vs. Embedded Cylinder Pipe *

	Lined Cylinder	Embedded Cylinder
Number of Pipe Sections	20,124	92,164
Number of Distressed Pipe Sections	413	3,780
Percent of Damage	2.1%	4.1%
Length of PCCP Inspected (feet)	362,232	1,658,952
Length of PCCP Inspected (miles)	69	314

* Not all 420 miles in database could be compiled due to partial data on some projects.

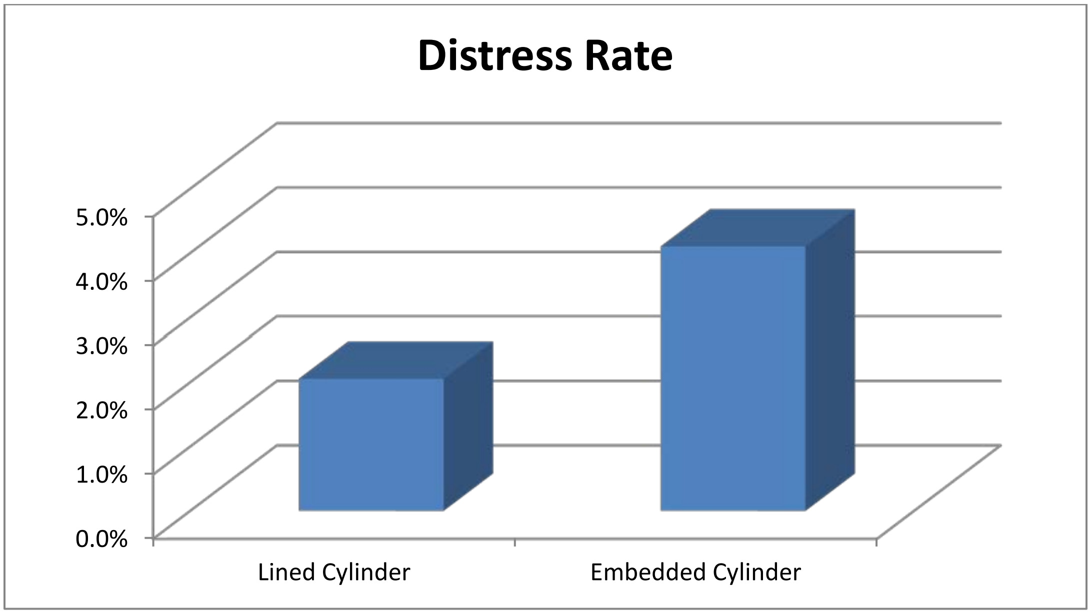

Figure 3- Lined vs. Embedded Cylinder

PRODUCT CONVEYED

Electromagnetic inspection of PCCP was initially developed for water transmission mains, but has also been applied to wastewater force mains and PCCP used in industrial settings, including power plants. The database was reviewed to compare rates of distress for pipelines conveying different types of product. This review found the wastewater force mains have a higher rate of distress than water mains or industrial pipelines. However, the amount of wastewater inspections is not as high as water inspections and these are typically focused on shorter length pipelines that are known to have had past problems. This may account for the higher distress rate in wastewater mains. Table 5 and Figure 4 summarizes this comparison.

Table 5

Comparison of Products Conveyed *

	Water	Wastewater	Industrial
Number of Pipe Sections	75,604	1,613	2912
Number of Distressed Pipe Sections	2,309	705	350
Percent of Damage	3.1%	43.7%	12.0%
Length of PCCP Inspected (feet)	1,360,872	29,034	52,416
Length of PCCP Inspected (miles)	258	5	10

* Not all 420 miles in database could be compiled due to partial data on some projects.

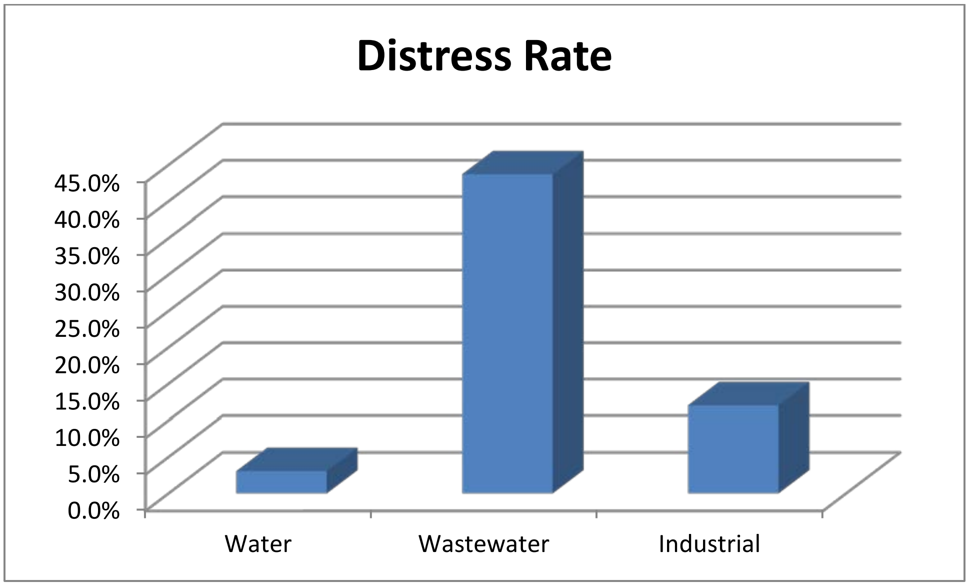

Figure 4- Distress by product conveyed

CONCLUSIONS

By reviewing of electromagnetic and acoustic monitoring database for more than 500 miles of PCCP the following significant conclusions can be made:

1. Average Distress Rate and Level of Damage: The average distress rate for PCCP mains is 3.9% as determined through the application of electromagnetic inspection and acoustic monitoring. Of the damaged pipe, 2.0% of the total population is considered to have low level of damage. This means that 98.6% of PCCP pipe sections have either no damage and are in like new condition or have low levels of damage and a low risk of failure. This low distress rate is encouraging, but it is important to find deteriorated pipe sections as it only takes one bad pipe section to generate a significant pipeline failure. This supports the "Assess and Address" approach to managing PCCP mains, whereby condition assessment can be used to find damaged pipe and various rehabilitation methods can be used to address the risk of moderate of low level of damage. If used properly, this management approach can restore pipeline risk to levels associated with new pipelines for a fraction of the cost of a large capital replacement project.
2. Vintages of Pipe: Distress rate is highest for pipes manufactured from 1972 to 1978. This is not a surprising finding as this is when PCCP with Class IV prestressing wire was manufactured, wire that is known to be of poor quality. However, pipe manufactured in from 1965 to 1967 and 1968 to 1971 also high distress rates that is approaching the 1972 to 1978 values. If Pre 1955 and Post 1992 eras are excluded due to low number of miles inspected, ultimately, it is clear that all eras have pipe sections with consistent wire break damage. It only takes one bad pipe section in a sensitive area or on a critical pipeline, to generate a significant disruption service or significant damage. Thus the data supports the case for proactive pipeline management, especially for critical pipelines or pipelines in sensitive/developed areas.
3. Embedded vs. Lined Cylinder Pipe: One of the more interesting findings that was observed in the data was that embedded cylinder pipe had a distress nearly twice that of lined cylinder pipe. The length of lined cylinder pipe included in the database was only 69 miles and single projects with low distress rates may have artificially lowered the distress rate for lined cylinder pipe. More investigation is warranted and will be performed to see if this conclusion is statistically valid.

REFERENCES

Analysis of Total Cost of Large Diameter Pipe Failures – AWWA Research Foundation Study, 2007

Failure of Prestressed Concrete Cylinder Pipe, American Water Works Association Research Foundation, Denver, Colorado: AWWA; 2007