Beyond the Wires

A Sustainable Approach to Prestressed Concrete Cylinder Pipe Management

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ABSTRACT

Recently the industry has been emphasizing broken prestressing wires as a basis for the management of Prestressed Concrete Cylinder Pipe (PCCP). The approach includes: evaluating broken wires, establishing a threshold level of broken wires for repair, and repairing only sections that exceed the threshold.

While evaluating wire breaks are an important part of PCCP management, it is important to acknowledge additional factors beyond wire breaks. By acknowledging additional condition factors, limitations of wire break assessment, and considering other rehabilitation approaches, there may be a more sustainable PCCP management approach (or combination of approaches). The approach may reduce risk and be more sustainable in terms of costs (current and future).

For some areas, the San Diego County Water Authority found the comprehensive rehabilitation approach, steel relining of PCCP, to be more sustainable in terms of costs. In addition, the approach significantly reduced the risk of a pipeline failure. However, in other areas, a localized, as-needed repair approach, such as Carbon Fiber, was more sustainable in terms of costs.

INTRODUCTION

Recently the industry has been focusing on broken wires for assessment of PCCP. In the last two years there have been eight publications highlighting this approach (Baird 2011; Higgins 2010; Jones 2010, Ojdrovic et al. 2011, Terrero et al. 2011, Wrigglesworth and Higgins 2010, Zarghamee et al. 2011a,b). Additional factors can greatly influence PCCP condition and consequence of failure. When Pipeline owners consider these additional factors, along with wire breaks and costs, a sustainable rehabilitation approach can be identified.

PCCP CONDITION - BEYOND WIRE BREAKS

With emphasis on wire breaks, owners may overlook other factors that affect the condition of PCCP. Other factors may lead to PCCP ruptures and leaks (hereon referred to as PCCP breaks) including the condition of the field joints. In addition, it is important to understand the limitations of wire break assessment technologies.

The cause of PCCP breaks are not always due to wire breaks. A comprehensive AWWA Research Foundation report on the Failure of PCCP (Romer et al. 2008) published a failure database with 592 entries from around the United States. Although the purpose of the database was not to identify root causes of PCCP failures, the database contains useful information regarding reasons for PCCP breaks. The database identified 435 PCCP breaks (Category 1 failures or catastrophic failures). Of the PCCP breaks identified, 112 had information suggesting that the cause was something other than wire breaks (See Table 1).

Table 1. PCCP Breaks

Potential Causes	Number of Breaks	Percent of Total Breaks
Unspecified	195	45
Wire Breaks	128	29
Other than Wire Breaks	112	26
Total	435	-

The reasons suggested in the database for PCCP breaks, other than wire breaks, have been summarized by the author in Table 2.

Table 2. Reasons (Other Than Wire Breaks) Suggested for Breaks

Potential Causes	Number of Breaks	Percent of Total Breaks
Joints - leaks, breaks, and looped gaskets	27	6
Surge events	26	6
Manufacturing defects, installation errors, and/or improper inspection	19	4
Thrust forces, excessive loading, and/or bedding defects	15	3
Cylinder - dents, welding defects and tears	10	2
Hydrogen sulfide internal corrosion	8	2
Improper design	4	1
Third-Party damage	3	1
Total	112	-

Based on the data, the main cause of PCCP breaks has been due to wire breaks, however other causes are significant. It is important to understand and address these factors because they can influence risk of PCCP breaks and impact the management and rehabilitation of PCCP.

Field Joint Conditions. The condition of joints is important. The Water Authority has experienced 12 PCCP breaks. Six of these PCCP breaks were caused by factors other than wire breaks, including two caused by corrosion at the joint and two caused by cylinder corrosion. External excavations on Water Authority pipelines have shown several joints with insufficient and/or poorly applied external mortar (See Figure 1).

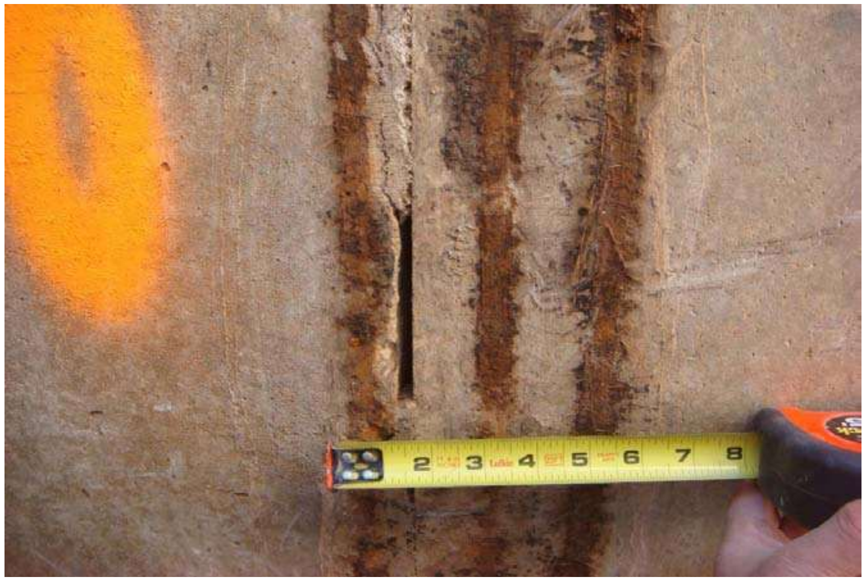

Figure 1 - Poor PCCP Joint Mortar

These defects allow moisture to penetrate to the joint ring and cause corrosion on the cylinder to joint ring weld and wires near the joint. This has led to PCCP breaks due to joint ring separation from the cylinder (Figure 2), cylinder corrosion and wire breaks near the joint as in Vidmar, et al. 2008.

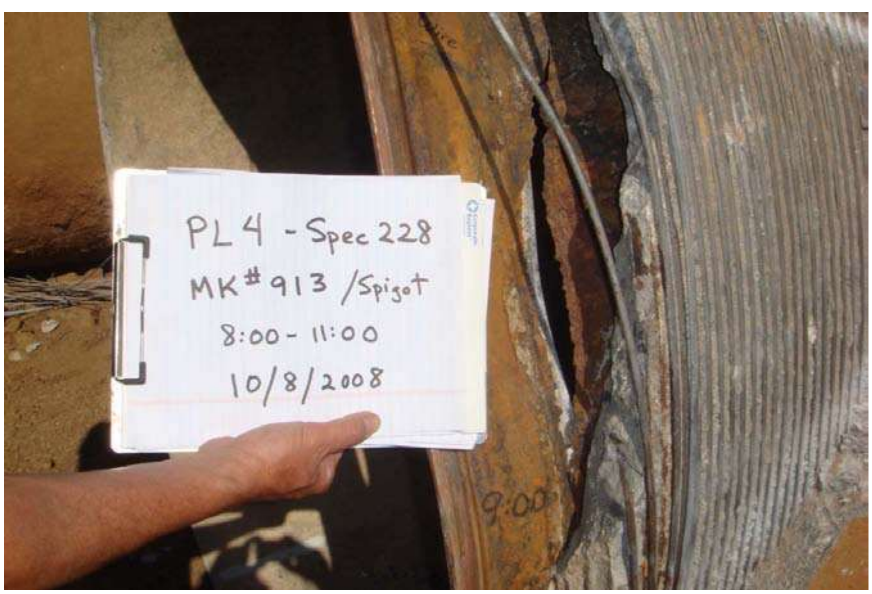

Figure 2 - Joint Ring Corrosion and Cylinder Separation

Wire Break Assessment Limitations. Owners need to be aware that wire break assessments with current non-destructive technologies (NDT) is limited. Although the information is a good estimate of broken wires, it may not be accurate for a number of reasons. Assessment of broken wires near the joint is not possible (Pure Technologies 2011). In addition, the number of wire breaks predicted using NDT relies heavily on proper signal calibration and accurate records from the owner which may not always be available (Ablin et al. 2008). Finally, additional wires may break during pipeline draining and refilling (Stroebele et al. 2010).

REHABILITATION APPROACHES - CONSQUENCE OF FAILURE

There are two main approaches to PCCP rehabilitation:

- Localized repairs such as Carbon Fiber Repairs (Moncrief, et al. 2001)
- Comprehensive repairs such as steel relining of long reaches (Fiori et al. 2001).

When managing PCCP, the selection of rehabilitation methods can be influenced by consequence of failure, which is based on many factors including location, hydraulics and system redundancy.

Location. The pipeline's physical location can affect the approach selected to rehabilitate the pipeline. For example, a pipeline may be in a rural setting with minimal potential for property damage in the immediate vicinity; however downstream drainage within an urban catchment may be insufficient to deal with the pipeline failure. This could result in flooding and subsequent property damage. Changing land use can also have an impact on rehabilitation selection. For example, an area alongside the Water Authority's pipeline has changed in the past 10 years from rural livestock grazing farmland, into densely populated communities and associated infrastructure (Figure 3).

Figure 3 – Changing Land Use Around Pipeline Alignment

This directly affects the assessment of potential for damage and increases the consequence of failure of the pipeline.

Recently the Water Authority rehabilitated a PCCP reach 4.5-kilometers [15,000-feet] in length using steel liners. The Water Authority chose to completely rehabilitate the entire reach because of the high consequence of failure. The pipeline was on a hill above a major interstate freeway. In addition, there were numerous properties on a hillside below the pipeline. While the Water Authority used acoustic monitoring of this pipeline as a safeguard, the ultimate goal was a significant reduction of risk. An as-needed repair approach would have not provided this reduction in risk.

Hydraulics. When considering rehabilitation methods, it is important to assess the hydraulics and operation of the pipeline. The pipeline might be currently operating under a gravity flow condition, however there may be operational changes. For example, in an emergency scenario some sections of the Water Authority's pipelines will be required to receive pumped flow (compared to gravity flow). The PCCP, as designed, should be able to operate under this scenario, however the condition of the PCCP has deteriorated. Therefore, the Water Authority selected a complete rehabilitation method to reduce the consequence of failure and risk under normal operation and mitigate any additional risk during an emergency condition.

System Redundancy. Due to the high costs of large diameter pipelines, a primary transmission system is rarely redundant. As a result, the pipeline is usually a critical supply. Therefore, there is a limited ability to shut down the pipeline for repairs.

The Water Authority operates the primary transmission system for most of San Diego County. The system has 132-kilometers [82-miles] of PCCP. Because retail agencies depend on the imported water supply from the Water Authority, interruptions are limited. Several pipeline shutdowns or sporadic shutdowns associated with localized repairs are not possible in most cases.

RISK AND COST - IDENTIFYING THE SUSTAINABLE APPROACH

By acknowledging additional condition factors to wire breaks, limitations of wire break information, and considering rehabilitation approaches based on consequence of failure there may be a more sustainable PCCP management approach (or combination of approaches). The approach may reduce risk and be more sustainable in terms of costs (current and future). The Water Authority has identified two distinct locations in its system with two different rehabilitation approaches. The Water Authority considers both sustainable. For the purposes of this document and simplicity, these PCCP pipelines will be referred to as Pipeline "A" and Pipeline "B" (See Table 3).

Table 3. Pipeline Information

Name	Length	Year Installed
Pipeline A	19-kilometers [12 miles]	1960
Pipeline B	18-kilometers [11 miles]	1982

It is important to note that these considerations are only a sample of the many factors involved in making rehabilitation decisions for the Water Authority.

Condition. The Water Authority has performed a condition assessment and actively monitors (acoustic technology) both pipelines. Pipeline A has had four PCCP breaks of which three were due to corroded and broken wires. Pipeline B has had no PCCP breaks. Table 4 summarizes the condition information.

Table 4. Pipeline Condition Summary

Name	Installation	Joint Mortar	Surge Potential	Sections with Wire Breaks	Wire Break Activity
Pipeline A	Poor	Poor	Low	15-percent	180 per year
Pipeline B	Moderate	Acceptable	Moderate	1-percent	10 per year

Consequence of Failure. The Water Authority evaluated some of the factors that influence the consequence of failure of these two pipelines. Table 5 summarizes these factors.

Table 5. Pipeline Consequence of Failure Summary

Name	Location	Hydraulics	Redundancy
Pipeline A	Urban – Critical Utilities nearby	Gravity – No Emergency Pumping	Limited
Pipeline B	Rural	Gravity – No Emergency Pumping	Limited

Risk. The risk is the product of condition and the consequence of failure. The Water Authority's goal is to reduce risk in a cost effective and sustainable way. The condition of Pipeline A is poor considering the original installation, joint quality, number of wire breaks, and wire break activity. Pipeline B's condition is better with regards to joint condition, wire breaks, and wire break activity. Pipeline A has a high consequence of failure due to the urban environment and critical utilities, such as electrical power and high pressure gas lines. Pipeline B has a lower consequence of failure because it is mostly in a rural area. Based on detailed qualitative analysis including several other factors the Water Authority evaluated, Pipeline A has a higher risk.

Cost. The Water Authority identified a 4.8-kilometer [3-miles] section from Pipeline A for a rehabilitation method cost comparison, the section had a 9-percent distress rate, or 9-percent of all pipe sections had one or more wire breaks. Based on the frequency of wire breaks, these sections will likely continue to degrade over the next 50 years.

The first rehabilitation approach considered is a localized rehabilitation. This approach will be conducted as-needed based on sections that exceed a threshold level of wire breaks. For this approach, the Water Authority assumed a total of 432-meters [1,440 feet], or 9-percent of the pipe, will need to be repaired over the next 50 years to address the current level of distress. The repairs of individual pipe sections are 6-meters [20 feet] long and are conducted as shown in Table 6.

Table 6. Assumed number of repairs per year through remaining lifespan

Rate of Repair	Years	Number of repairs	Distance repaired
1 repair every 2 years	2011 through 2020	5	30 meters [100 feet]
1 repair per year	2021 through 2038	18	108 meters [360 feet]
2 repairs per year	2039 through 2055	34	204 meters [680 feet]
3 repairs per year	2056 through 2060	15	90 meters [300 feet]
	Total	72	432 meters [1,440 feet]

The costs for the as-needed repair approach would be between $45-million and $110-million (assuming a range of annual price escalation and inflation combined between 2.5-percent and 5-percent). Acoustic monitoring would be required for the life of the pipeline for this approach. These additional maintenance costs have not been included in the analysis.

The second approach considered would be a comprehensive rehabilitation for the entire reach. The cost for this rehabilitation is estimated at $29-million. Bond financing for this would result in a total cost of $60 million at the end of a 30-year lending period. Table 7 and Figure 4 shows a cost comparison for these two approaches.

Table 7. Example Comparison of Costs for Rehabilitation Methods

Rehabilitation Approach	Interest or Escalation plus Inflation Rate	Lifetime Total Cost
Localized, As-needed	2.5-percent	$45-million
Localized, As-needed	5-percent	$110-million
Comprehensive	5.5-percent	$60-million

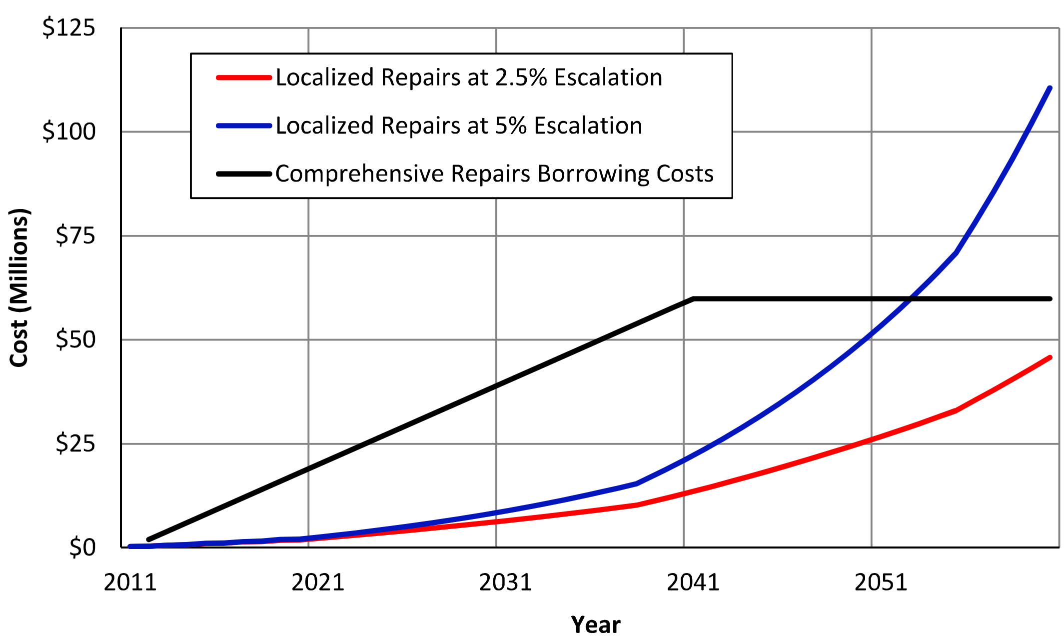

Figure 4 - Cost Comparison of As-Needed vs. Comprehensive Rehabilitation

Risk Reduction. For the localized rehabilitation approach, risk would be reduced in only 432-meters [1,440 feet] of the 4.8-kilometer [3-mile] section. Other condition and consequence of failure factors would still be present in other, non-rehabilitated, parts of the pipeline. After 50-years, there would still be the same potential for PCCP breaks due to factors other than wire breaks. Because a significant level of risk is still present, it should be noted that if a failure did occur, this could add significantly to the overall costs for this option.

For the comprehensive rehabilitation, the reduction of risk would be implemented over the entire 4.8 kilometers [3-miles]. The overall risk would be significantly reduced due a significant mitigation of additional condition factors (joint conditions and installation defects) and the consequence of failure factors.

Sustainability. For the Pipeline A section, the comprehensive rehabilitation approach is more sustainable over 50-years in terms of cost and the reduction of risk is significantly greater. Future generations are left with an asset that has an extended serviceable life.

For Pipeline B, which has 1-percent distress, the as-needed rehabilitation approach may be more sustainable in terms of cost. Similar to the analysis above, this approach would cost between $11.1-million and $11.8-million depending on escalation and inflation. This would be significantly less than the comprehensive rehabilitation approach at a cost of $60-mllion. Also the risks for this pipeline are currently at an acceptable level based on the condition and consequence of failure. The continuous monitoring for wire breaks will be important to monitor the risk of wire breaks. Based on the condition and potential changes in the consequence of failure, there may come a time when the comprehensive rehabilitation approach should be implemented.

CONCLUSION

By acknowledging additional condition factors, limitations of wire break information, and considering other rehabilitation approaches based on consequence of failure, there may be a more sustainable PCCP management approach (or combination of approaches). The approach may reduce risk and be more sustainable in terms of costs (current and future). For a sample case, the Water Authority found the comprehensive rehabilitation approach to be more sustainable in terms of costs. In addition, the approach significantly reduced the risk of a pipeline failure. However, in other areas a localized, repair as-needed approach was more sustainable in terms of costs.

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