When to Intervene? Using Rates of Failure to Determine the Time to Shut Down Your PCCP Line.

Mike Wrigglesworth; Pure Technologies, 300-705 11th Ave SW, Calgary, AB, Canada, T2R 0E3; +1.403.266.6794

Michael S. Higgins, P.E.; Pure Technologies, 8920 State Route 108, Suite B; Columbia, MD 21042; 443-766-7873

INTRODUCTION

Performing structural evaluations of aged civil engineering structures has traditionally been performed on a static basis. The condition of the structure is tested either destructively or non-destructively to determine its present day condition and the strength is evaluated to determine if the structure can safely withstand anticipated loads.

One of the problems with managing structures in this fashion is that structures do not behave in a static fashion. This is especially true for large diameter PCCP (Prestressed concrete cylinder pipeline) mains that have wire break damage resulting from corrosion or cracking from hydrogen embrittlement.

Given the variability in rate of deterioration in a PCCP main the risk associated with a pipe section changes with time. Pipe sections where risk is deemed to be acceptable may change to a point where risk is not acceptable in a relatively short duration of time. This phenomenon has been observed on multiple pipe sections.

This paper examines the rate of deterioration of PCCP mains to evaluate how risk changes or does not change with time and how this information can be used to determine when a pipeline should be repaired.

MEASURING DETERIORATION IN PCCP MAINS

As presented in many technical papers, most of the efforts on assessing PCCP mains and determining the extent of deterioration is focused on detecting the quantity and/or rate of wire break damage in the prestressing wire wrapping. This is accomplished using two methodologies:

1. Electromagnetic inspection: This technique involves obtaining a magnetic signature of each pipe section in a subject main and evaluating this signature to identify magnetic anomalies associated with wire break damage. The anomalies are evaluated to estimate the number of broken wire wraps in each section of PCCP. Wire break estimates are often used in structural engineering models to determine the risk of failure. This assessment technique provides a good understanding of the pipe the day it was inspected, but does not provide any information on the rate of deterioration.

2. Acoustic monitoring: This technique involves installing instrumentation on a pipeline that is capable of continuously monitoring acoustic activity in a pipeline to identify the acoustic event associated with a breaking prestressing wire. It essentially records and identifies wire breaks as they occur in the pipeline. Since it is detecting wire breaks over time, a rate of deterioration is established, but the technique does not provide an estimate on the total number of wire breaks in a pipe section unless acoustic monitoring is installed following an electromagnetic inspection.

Since acoustic monitoring does not provide a total number of wire breaks, it is not as clear when it is necessary to intervene with repair strategies. However, by examining a historical database acoustic monitoring on PCCP mains, conclusions can be made as to when to intervene with repair strategies.

ACOUSTIC MONITORING DATABASE

The database that was examined as part of this technical paper is maintained by Pure Technologies and includes acoustic monitoring data from more 40 water and wastewater utilities. Acoustic monitoring data from 470 miles of PCCP is contained in the database, including 43,278 wire breaks. The total number of PCCP pipe sections represented in the database is 137,063.

Based on reviewing the database, pipe sections were divided into several categories and examined to provide input on the behavior of PCCP mains. The categories include:

1. Pipe sections with acceptable risk and a low rate of deterioration
2. Pipe sections with acceptable risk and a high rate of deterioration
3. Pipe sections with high rate of deterioration but did not undergo internal inspection
4. Pipe sections exhibiting non linear rates of wire break activity
5. Pipe sections exhibiting increased rates of wire break activity following depressurization or repressurization

PIPE SECTIONS WITH ACCEPTABLE RISK AND A LOW RATE OF DETERIORATION

Acceptable risk constitutes a pipe section that has undergone an electromagnetic inspection and has some level of wire break damage, but based on the quantity of wire break damage and structural modeling results, the risk of failure is acceptable. Pipe sections in the database in this category were estimated to have at least 5 wire breaks. Wire break estimates were as high as 100 wire breaks. As a result of an apparent acceptable level of risk, these pipe sections are returned to service. For the pipe sections in this category acoustic monitoring was implemented following the inspection and the rate of wire break activity was low, 0 to 0.5 wire breaks per year.

In excess of 98% of pipe sections with wire break damage as reported by electromagnetic inspection (includes data from both firms that perform this inspection method) do not have any additional wire break damage as detected by the acoustic monitoring system. This would indicate that these pipe sections have exhibited wire break damage at some point during their service, but the conditions that led to the wire breaks have changed and the pipe sections have reached a point of equilibrium and the pipe sections are behaving with minimal risk.

An example of one of these pipe sections is a pipe that had five wire breaks as determined during an internal electromagnetic inspection. Upon excavation of the pipe section, a gouge was identified on the side of the pipe at the location reported by the electromagnetic inspection. The gouge was likely from the original construction.

PIPE SECTION WITH ACCEPTABLE RISK AND A HIGH RATE OF DETERIORATION

Based on electromagnetic inspection and structural modeling, these pipe sections had an acceptable level of risk, but upon returning to service exhibited a high rate of deterioration (greater than 0.5 wire breaks per year). These pipe sections are of particular interest as these pipe sections may be approaching a point of failure and may not be in a state of equilibrium. These pipe sections should be identified and carefully watched to ensure they do not fail. Three examples of these pipes in the database include.

- Great Manmade River Pipe Section TB 279+50
- San Diego County Water Authority Pipe Section that Failed

Great Manmade River Pipe Section TB 279+50

A pipe section located at Station 279+750 on the TB line was not considered for replacement or repair based on results from the baseline condition assessment performed in 2001. An acoustic monitoring system was installed in December 2003 and wire breaks were almost immediately recorded on this pipe section. After one year of monitoring over 100 wire breaks had been recorded (Figure 4.1).

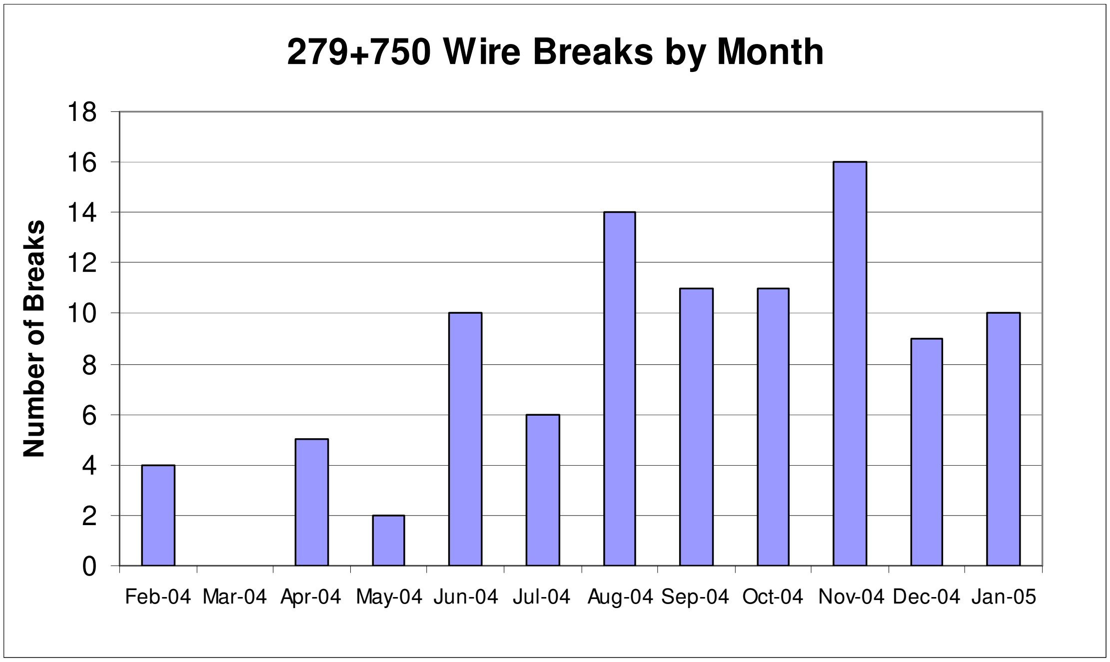

Figure 1: Wire breaks on pipe 279+750

Based on this data, the pipeline was shutdown and the pipe section was repaired using external post-tensioning. Forensic investigations of the exposed pipe identified 148 wire breaks in the pipe section. Evaluating the rate of deterioration data for this pipe section was credited with preventing a likely rupture. Figure 5.1 shows photos of the pipe section exposed prior to its repair, divided by meter.

It is likely that corrosion had started on this pipe when electromagnetic inspection was performed, but had not developed of the point of significant wire break damage. However, within three years, the rate of wire break damage increased significantly.

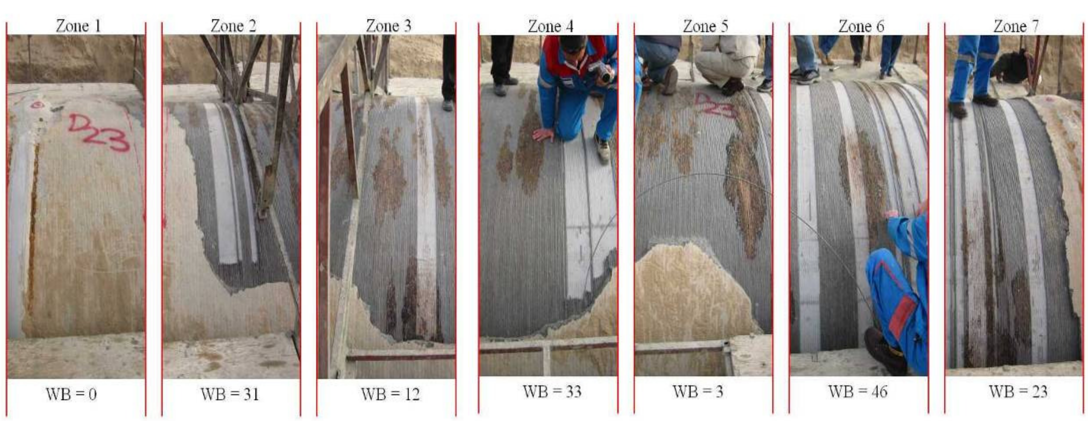

Figure 2: Photos of forensic investigation of pipe 279+750

San Diego County Water Authority Pipe Section

This pipe section was estimated to have 15 wire breaks during an internal electromagnetic inspection. Acoustic monitoring of the pipe section was performed following returning the pipe to service. Within a month of pressurizing the pipe, a series of wire breaks were detected by the acoustic monitoring system. Slow communications impeded data transmission and timely notification of these events and the pipe section failed in close proximity to a joint. This failure provides information on the rate of failure immediately prior to a rupture. In the week leading up to the rupture, 21 wire breaks (rate= 91 wire breaks per month) were recorded. In the day prior to the failure, 17 wire breaks were recorded. A plot displaying the wire breaks detected by the acoustic monitoring system is shown in Figure 3.

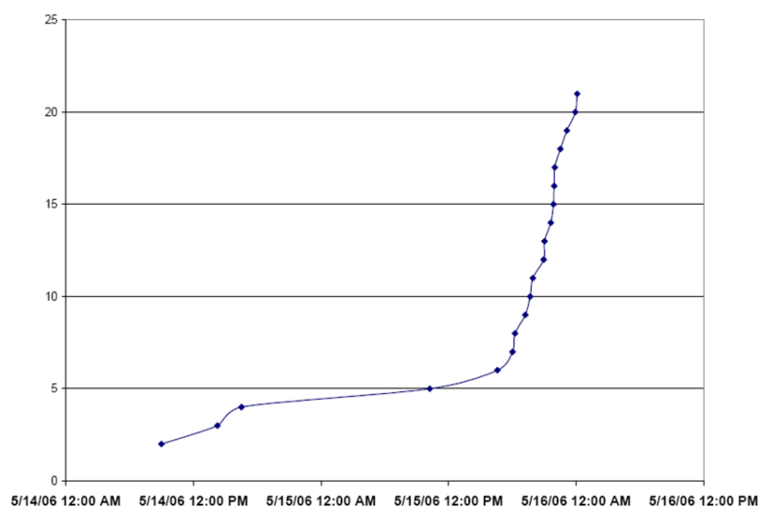

Figure 3: San Diego County Water Authority wire breaks leading up to failure

PIPE SECTIONS WITH HIGH RATE OF DETERIORATOIN THAT DID NOT UNDERGO INTERNAL INPSECTION

In some instances acoustic monitoring has been used prior to or in lieu of electromagnetic inspection to determine the condition of a PCCP main. In these cases, the only means to identify pipe sections in need of repair is to evaluate the rate of deterioration. Data from four case studies is presented below.

- Pinellas County Belcher Road Main
- Tampa Bay Water Cypress Creek Main
- Howard County Ridge Road Main
- Greater Lawrence Sanitary District Pipe Section #22

Pinellas County Belcher Road Main

The Belcher Road PCCP transmission main is approximately 3 miles long and is situated under a major roadway. Acoustic monitoring of this pipe section was performed on the pipeline for a total of 133 days. Wire breaks were detected on 119 pipe sections during the monitoring period. The quantity of wire breaks on each pipe section ranged from one wire break to 54 wire breaks, making the rate of wire breaks on the pipeline ranging from 0 to 12 wire breaks per month. Pipes sections with high rates of deterioration were subsequently to confirm the wire break damage and repaired. Photos from these pipe section are shown in Figure 4.

Figure 4: Pinellas County pipe sections

Tampa Bay Water Cypress Creek Main

In 1999, acoustic monitoring was used to detect wire breaks for a period of 60 days on 5 miles of 84-inch PCCP. During this time, 221 wire breaks were recorded on 24 pipe sections. More than five wire breaks were recorded on six pipe sections. The rate of wire breaks for these pipe sections was 3.5, 4, 5.5, 6, 8.5, and 62 wire breaks per month. Since the pipeline could not be taken out of service, it was not repaired based on this data. One of the pipe sections with an increased rate of wire break activity failed in 2004. Subsequently, the entire pipeline was replaced.

Howard County Ridge Road Main

The 42-inch PCCP main in Howard County, MD was acoustically monitored three times to determine rate of deterioration. The duration of monitoring for each of these times was 119 days, 551 days, and 520 days in 2000, 2004 to 2005, and 2006 to 2007 respectively. One pipe section was detected to have on going wire break activity in each of these monitoring periods. The rates of deterioration were measured to be 3.5 wire breaks per month, 0.9 wire breaks per month, and 0.6 wire breaks per month respectively. This pipe section was excavated in late 2006 to implement repair strategies. Upon excavation and forensic evaluation, nearly every wire wrap on this pipe section was broken (see Figure 5).

It is believed that the reason the pipe had not failed was that the principal deterioration mechanism was hydrogen embrittlement induced cracking of the prestressing wire. This resulted in numerous broken wire wraps, but the position of the breaks were dispersed around the circumference, which reduces the structural significance of the wire breaks compared to corrosion induced wire breaks where the damage is usually contiguous.

Figure 5: Ridge road main in Howard County

Greater Lawrence Sanitary District Pipe Section #22

Pipe Section #22 of a 72-inch PCCP main was acoustically monitored for 260 days during which 14 wire breaks were recorded, a rate of 0.6 wire breaks per month. Afterwards the pipe was excavated and a large area of mortar delamination and cracking was observed on the springline of the pipe section. The pipe was strengthened with post tensioning tendons (see Figure 6).

Figure 6: GLSD Pipe Section 22

PIPE SECTIONS EXHIBITING NON LINEAR RATES OF WIRE BREAK ACITIVITY

By examining the rate of wire break information in the database it is apparent **that wire breaks do not occur in a linear or predictable fashion**. Wire breaks appear to occur in clusters when a group of wire breaks occur in a short period of time followed by long periods of time where no wire breaks occur. This is most likely due to the deterioration mechanism creating a location on the pipe where it is temporarily unstable. This leads to one wire break which places additional stress on nearby wires which may then break shortly thereafter. Once the pipe location reaches a state of equilibrium, wire breaks do not occur for a longer period of time until the deterioration mechanism has sufficient time to generate another unstable condition, at which time another cluster of wire breaks occurs.

This type of wire break distribution has been observed on many pipe sections and results in a wire break total that looks more like a staircase than a linear function. The following figures (Figure 7-10) display examples of this effect.

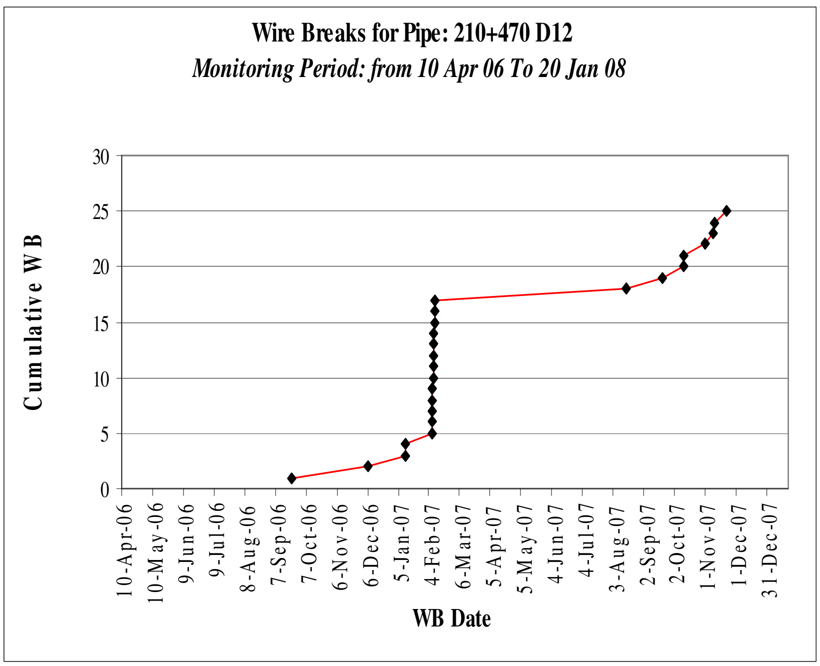

Figure 7: Non-Linear Wire Break Activity at Pipe 210+470 D12

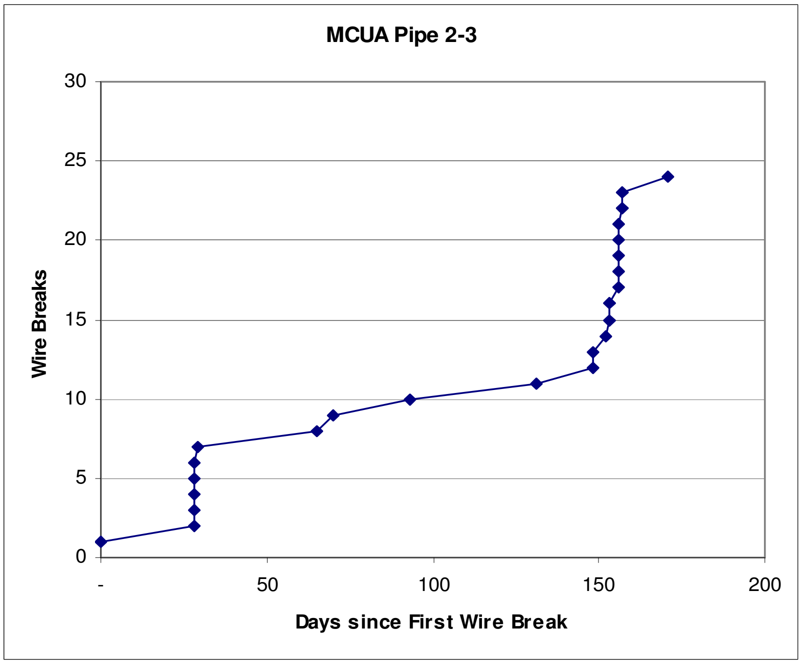

Figure 8: Non-Linear Wire Break Activity at MCUA Pipe 2-3

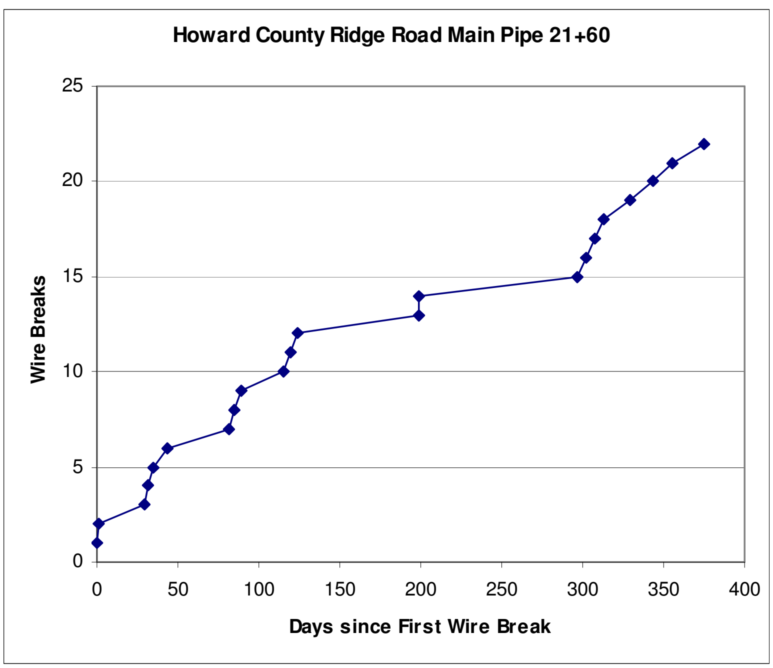

Figure 9: Non-Linear Wire Break Activity at Howard County Pipe 21+60

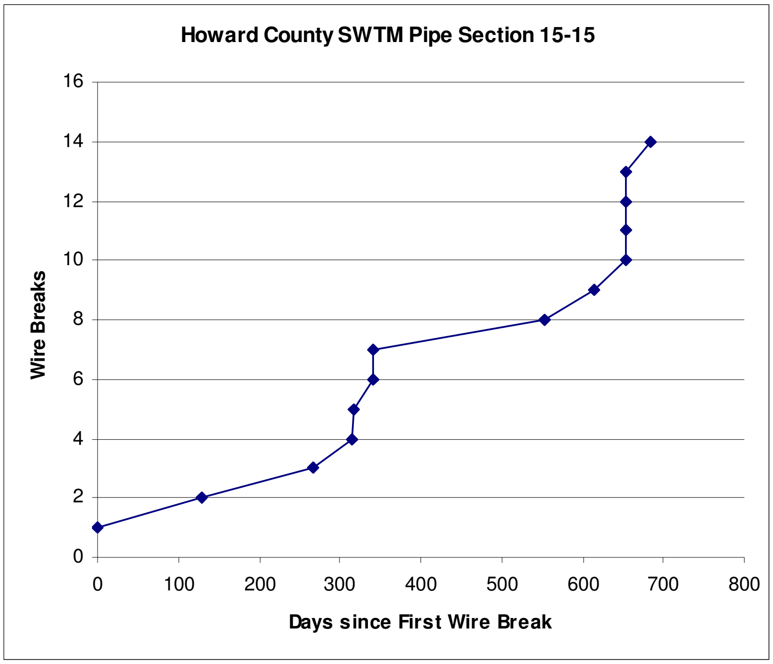

Figure 10: Non-Linear Wire Break Activity at Howard County Pipe 15-15

PIPE SECTIONS EXHIBITING INCREASED RATES OF WIRE BREAK ACTIVITY FOLLOWING DEPRESSURIZATION OR REPRESSURIZATION

By reviewing the database in conjunction with known times when a pipeline was de-pressurized or re-pressurized, multiple instances have been observed where the rate of wire break activity rapidly increases for a relatively short period of time following the de-pressurization or re-pressurization. The reason that this is believed to occur is because upon depressurization the pipe elastically deforms in such a manner that wire stress is reduced as pressure is decreased. This results in strain in the wire that is reversed when the pipe is re-energized. For locations where the prestressing wire was cracked and/or pitted to the point where it was already near failure, this loading and unloading of the prestressing wire is believed to accelerate the crack or pit to the point of breakage either during de-pressurization or re-pressurization.

Figure 11 shows an example of a pipe that experienced an increased rate of wire break activity during pressurization.

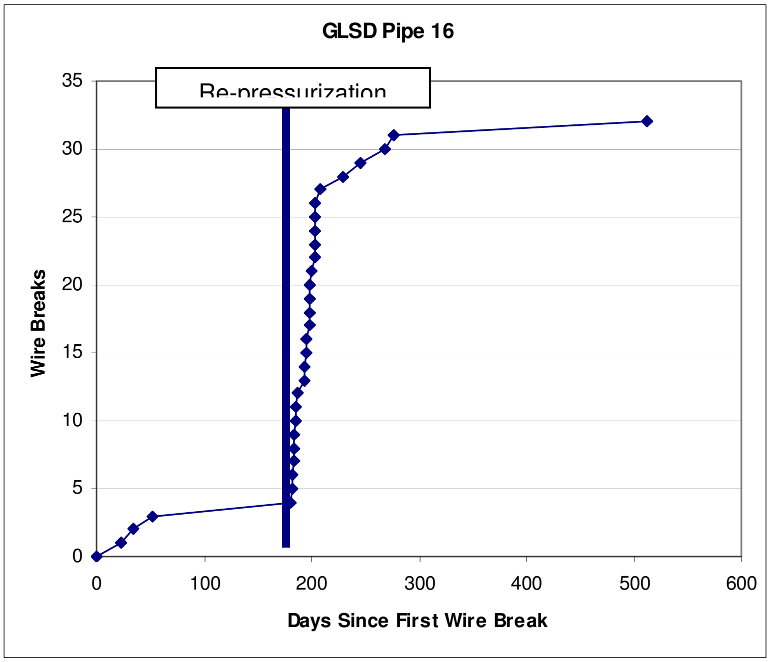

Figure 11: GLSD wire breaks observed following re-pressurization

CONCLUSIONS

Based on the observations made by reviewing historical rates of wire break activity, in PCCP mains, several conclusions can be made:

- No set threshold for intervention can be established based on rate of wire break activity for PCCP that would be applicable to all PCCP mains. The rate of wire break activity requiring intervention will depend on numerous variables including pipe design, loading conditions, consequence of failure, and a PCCP owner's tolerance for risk.
- The case studies above demonstrate that rate of wire break activity can be used to predict the general condition of a PCCP pipe section.
- A wire break rate of 91 wire breaks per month was observed prior to the San Diego County Water Authority failure. This wire break rate is obviously indicative of a pipe near or in a state of failure.
- Other pipe sections which were identified and repaired prior to failure displayed wire break rates ranging from 0.6 to 62 wire breaks per month. Several of these pipe sections were excavated and found to be in a state of significant distress. This would suggest that wire break rates exceeding 0.5 wire breaks per month over extended periods of time should be cause for concern for a pipe section.
- The duration which increased rates of deterioration occur in a PCCP pipe section is important in determining the condition of a pipe. If wire breaks are

occurring over multiple years, data would suggest these pipes are in a significantly deteriorated condition.

- To accurately determine wire break rates to identify pipes of concern, acoustic monitoring programs should be of sufficient duration. To obtain a realistic measure of wire break rates acoustic monitoring programs should last at least 3 months, but the longer the monitoring program, the better understanding of the pipe. An alternative method to obtain rates of wire break information would be to perform electromagnetic inspections periodically (perhaps every year).
- By reviewing the database, it is apparent that repair priorities are often adjusted based on reviewing rates of deterioration. Following an internal inspection, pipes are usually prioritized by the total number of wire breaks. In most cases these pipe sections are in a state of equilibrium and are not changing. Pipes with lower total numbers of wire breaks (based on electromagnetic inspection), but with higher rates of wire break activity are often brought to the top of the priority list.

REFERENCES:

Bell, G., Paulson, P., Moore, C. (2009), "Use of Acoustic Monitoring Data for PCCP Condition Assessment", Proceedings of the ASCE Annual International Conference on Pipeline Engineering and Construction, San Diego, California

Essamin, O., El-Sahli, K. and Hovhanessian, G. (2004), 'The Great Man Made River Management System: A Pipe Risk Management System (PRMS) for Prestressed Concrete Cylinder Pipe: How an Expert Model and Monitoring Extend a Pipeline Lifespan at Lower Cost', Proceedings of the ASCE Annual International Conference on Pipeline Engineering and Construction, August 1-4, San Diego, California.

Galleher, J., Holley, M., Shenkiryk, M. (2009), "Acoustic Fiber Optic Monitoring, How it is Changing the Remaining Service Life of the Water Authority's Pipelines", Proceedings of the ASCE Annual International Conference on Pipeline Engineering and Construction, San Diego, California

Lenghi, A., Amaitik, N., Wrigglesworth, M. (2008) "Expansion of Existing Monitoring System on Great Man-Made River Project Using Acoustic Fibre Optic Technology", Proceedings from International Water Association Annual Conference, Vienna, Austria

Lewis, Richard (2005), "Corrosion of Prestressed Concrete Cylinder Pipe: History of Failures / Corrosion Issues", Workshop On Managing And Assessing PCCP Mains, June 24, 2005, Andover, MA