NDT CORPORATION
Nondestructive & Geophysical Testing

Measuring the Condition of Prestressed Concrete Cylinder Pipe

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Introduction

Prestressed Concrete Cylinder Pipe (PCCP) is a complex composite structure. For the pipe to function properly, all elements of the structure have to perform as intended. Sonic/ultrasonic testing can be used to evaluate these elements in PCCP. Failures of any elements of the composite structure such as a reduction in the concrete core strength, a delamination between layers of the composite structure, micro-cracking or cracking of the core, indicate the pipe section is not functioning as intended therefore compromising structural integrity.

Many factors singularly or in combination can shorten the service life of PCCP, including:

- Defective manufacturing materials and/or manufacturing methods
- Aggressive ground/groundwater environment
- Operational parameters that exceed the pipe design
- Improper design
- Improper installation

In addition to identifying structural deficiencies in initial tests, by evaluating the condition of PCCP over time using sonic/ultrasonic testing, a pipeline's aging process can be monitored. This allows the estimation of the pipes remaining useful service life and provide for effective pipeline management.

How Sonic/Ultrasonic Testing Works

Sonic/ultrasonic non-destructive testing has been a standard method used for evaluating the properties of concrete for over 60 years and successfully used for over 20 years to determine the structural condition of the concrete core and coating of PCCP.

Sonic/ultrasonic nondestructive measurements are made by creating an acoustic stress wave in the sonic/ultrasonic frequency band with an impact and measuring the transmission velocity of compressional and shear waves and resonance (impact echo) from the exterior surface of the pipe or from delaminations within the pipe. The transmission velocity values determine the elastic deformational characteristics of the concrete, an empirically determined calculated strength value and a direct measurement of the condition of the core concrete. The reflected signals resonate at a frequency that is related to the radial thickness and compressional wave velocity of the concrete core and coating. Because the average thickness of the pipe's wall is known, the average strength of the concrete pipe core, as well as the presence of delamination, can be determined from the measured resonant frequency and wave attenuation.

This testing provides information to determine if the pipe is functioning as designed or if conditions exist that indicate the pipe is deteriorating, including:

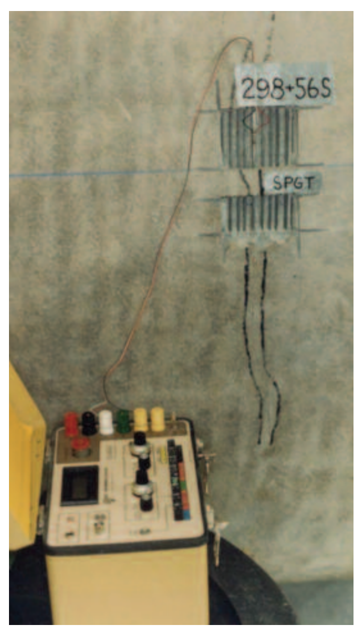
- Wire Breaks
- Loss of Prestressing
- Overloading
- Steel Cylinder Yielding
- Compromised mortar coating

Wire Breaks

Tests on an out-of-service 60-inch diameter PCCP pipe to detect broken wires, shows the effectiveness of sonic/ultrasonic measurements in detecting cut pre- stressing wires. With cuts in eleven, five and six wires in different locations, sonic/ultrasonic measurements were made along continuous line of coverage across all three wires cut locations. The mortar coating on both sides of the cut wires was well bonded to the pre-stressing wires.

Sonic/ultrasonic measurements effective in detecting cut pre-stressing wires; subsequent tests indicate that the mortar coating and adjacent uncut wires kept the pre-stress in tension away from the cut areas. *Image courtesy of Lewis Engineering and Consulting, Inc.*

The sonic/ultrasonic test results indicated loss of full thickness resonant frequencies for data acquired directly over cut wires and no change in velocity or resonant frequency data for measurements where wires were not cut indicating the affect of the broken wires was confined to the cut wire areas. These measurements were repeated on an annual basis for six years with no significant changes in velocity values or resonant frequency results, indicating that the mortar coating and adjacent uncut wires had kept the pre-stress in tension away from the cut areas.



Strain gauge measurements confirm residual tensile stress in the pre-stressing wire is below half of the ASTM specified minimum ultimate tensile strength as detected by sonic/ultrasonic measurements. *Image courtesy of Lewis Engineering and Consulting, Inc.*

These test results are borne out in the field. An electromagnetic and sonic/ultrasonic survey inspection conducted on a 66-inch PCCP pipeline indicated that a broken wire condition existed and excavation and destructive testing indicated that the actual number of broken wires were four. These wires were beneath gouge in the coating that occurred during pipe installation forty years ago. The wires had no corrosion outside the area that the coating was gouged and no signs of coating delamination. It is interesting to note that the gouge in the coating did not “grow” with time. The sonic/ultrasonic testing indicated that the coating was not delaminated and the strength of the concrete had not been reduced. Based on the results of a finite element analysis, no delaminations or micro cracking should occur with the low number of broken wires. Sonic/ultrasonic testing at another location on the pipe indicated a delamination at the spigot end of the pipe. The prestressing wire in contact with the core shows signs of significant corrosion indicating the passivation effect of the concrete is compromised.

Above this position corrosion was not present. This finding holds significance for this utility since the majority of the pipe ruptures experienced have occurred at the spigot end at the position of noted wire corrosion. Future sonic/ultrasonic surveys can document the progression of the noted corrosion.

Loss of Prestressing

Field measurements made on 1,062 108-inch diameter PCCP pipes for a major east-coast metropolitan water authority demonstrated the effectiveness of sonic/ultrasonic testing to identify pipe with loss of pre-stressing. Testing indicated two pipes had a loss of full thickness resonant frequencies, low velocity values and poor signal attenuation. The combination of these sonic/ultrasonic signal characteristics indicate the pipe was substantially compromised. These pipes were exhumed and destructively tested. Visual inspection of the exterior of pipe indicated a crack at the spring line of one pipe. Strain gauge measurements indicated that the residual tensile stress in the pre-stressing wire is 45.8 percent of the ASTM specified minimum ultimate tensile strength compared to the normal pipe manufactures wrapping stress of 75 percent. Subsequent demolition of the pipe revealed that there were six splices in one half length of the pipe, an unusually high number for PCCP and possible reason for the low tension in the pre-stressing.

Sonic/Ultrasonic Data Analysis of a 96-Inch Diameter PCCP

A tremendous amount of data concerning the structural condition of each pipe segment in a pipeline is developed by the sonic/ultrasonic testing. To accurately classify the anomaly in terms of the type and severity, a system was developed. With this system, a consistent and accurate method is used to evaluate the condition of each pipe. The sonic/ultrasonic testing results are very repeatable. By performing subsequent surveys and reducing the data using the classification system, pipe decay can be accurately monitored over time.

A simplified approach was developed to display the reduced data visually (Figure 1).

Based on structural condition of the pipe, pipe anomalous are separated into four (4) major areas of occurrence:

- Anomalies occurring at pipe ends - Represented as "E"
- Anomalies occurring over a significant portion of the pipe - Represented as "OS"
- Isolated anomalies occurring in the center section of the pipe - Represented as "C"
- Coating thickness reduction - Represented as "CR"

Figure 1.

Sub-set of test results for a 96-inch PCCP pipeline tested at 8-, 13-, and 22-year intervals using the sonic/ultrasonic method.

Image courtesy of NDT Corporation.

Defect Rating	
	Level 1 Anomaly
	Level 2 Anomaly
	Level 3 Anomaly
	Level 4 Anomaly
	Level 5 Anomaly
	Level 6 Anomaly

Pipe End Defects	E
Defects Occurring Over Most of Pipe	OS
Defects Occurring Outside Pipe Ends	C
Reduction in Pipe Thickness	CR

96' PCCP				
	Year Tested			
	1995	2000	2009	
Pipe #	Pipe Rating	Pipe Rating	Pipe Rating	Decay Rating
D203	0	0	0	1
D204	0	0	0	1
D393	0	0	OS	3
D394	0	0	OS	3
D394	0	0	E	4
D395	0	0	OS	3
D396	0	0	OS	3
D396	0	0	E	5
D397	0	0	OS	5
D398	0	0	E	5
D398	0	0	OS	3

96-Inch Diameter PCCP

96-inch PCCP pipeline installed in 1987 was tested in 1995, 2000, and 2009 using the sonic/ultrasonic method. Figure1 shows a small portion of the reduced testing data. As can be seen, the pipe contained no anomalies from time of installation to the testing that was conducted in 2000. Essentially the pipe lengths were in satisfactory condition during this span of time showing no anomalies. From the testing conducted in 2000 and 2009, some pipes have shown significant deterioration. Pipes D396 and D398 showed significant deterioration at pipe ends. These pipes were not excavated but based on similar end anomalies of pipe excavated, probably two feet of wire are significantly corroded and the mortar coating is separated from the core. Pipe D397 indicates significant deterioration occurred over a large portion of the pipe. This pipe was not excavated but based on excavation of similarly rated pipe; probably three to four feet of wire are corroded near the bottom of the pipe and possible delamination of the coating. Pipes D393, D394, D395, D396, and D398 are losing wire prestressing, while pipe D397 has lost a significant amount of wire prestressing. The results indicate that pipe sections are aging and the rate of deterioration appears to be accelerating and is shown.

Overloading

Pipe overloading conditions may occur because of poor bedding, surges, increased soil cover or an inadequate level of wire prestressing. Sonic/ultrasonic testing indicates these conditions by a loss of pipe thickness resonant frequencies for most, or the entire, pipe, but with velocity values in a range considered normal for PCCP. These results indicate the core concrete is micro-cracked, but not at a level that the core concrete strength has been significantly affected. Sonic/ultrasonic test results of major western city's 60-inch main that failed as the results of a surge indicated similar results: loss of the full thickness resonant frequency values with velocity values in a range considered normal for in compression pipe. In cases where the pipe is significantly overloaded, core concrete strength is significantly compromised indicating cracking and delamination between layers.

Testing of the previously mentioned 108-inch main indicated several consecutive pipe sections with a loss of the full thickness resonant frequency values, but with velocity values in a range considered normal for compression pipe. The project specifications required that the rock be excavated for two feet below the bottom of the pipe and granular fill be placed to the pipe spring line. Excavation of several pipe sections indicated that the pipes were resting on bedrock. The pipe being bedded on a point load resulted in the pipe being significantly under-designed.

Deterioration Rate

The pipe characteristics (concrete strength, degree of micro-cracking, delamination, and inference of broken wires) that sonic/ultrasonic testing measures and the repeatability of these measurements make this technique an excellent tool to establish the deterioration rate of PCCP pipes. Comparing currently collected sonic/ultrasonic data compared with previously collected data determines the decay rate and characteristics of aging/weakening pipe. Experience shows that many pipes have defects that do not get worse with time and consequently are not of a high concern. However, pipes that become significantly worse over time will likely continue to decay at a high rate based on the condition of the pipe.

Testing During PCCP Manufacturing and Installation

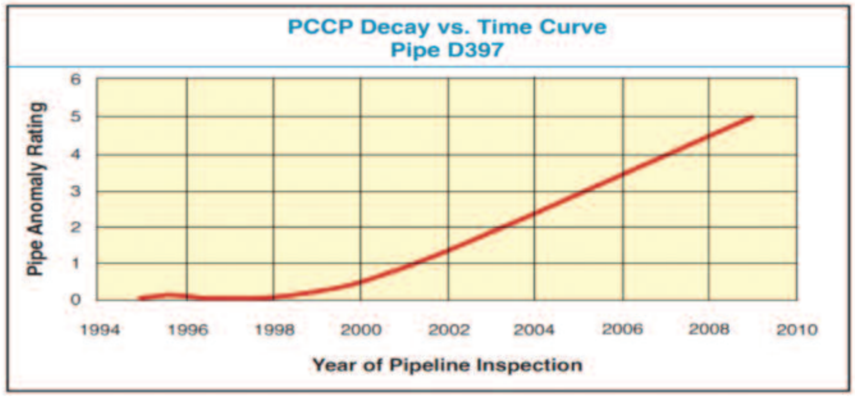
Many pipe defects are caused during manufacturing or installation. To understand the variance that may occur during the manufacturing process, an extensive sonic/ultrasonic testing program was conducted at a PCCP manufacturer's yard. This testing program included testing of lined and embedded cylinder PCCP during all phases of construction. In addition, contractor damaged pipe and other removed pipe provided by a local utility were included in the testing program. The sonic/ultrasonic testing results showed that problems resulting from manufacturing defects such as poor coating bond, wire splice where full prestress was not reestablished, low wire prestress, and concrete core damage and handling damage can be detected prior to installation.

As part of the testing program, a pipe section was returned to the manufacturer because it was rejected by the installation inspector. The 96-inch diameter pipe had been dropped by the contractor. There was no visible damage to the pipe. Sonic/ultrasonic testing determined that the concrete core was severely cracked with delaminations of the mortar coating. Undetected, this pipe probably would fail before its design life expectancy.

Conclusion

Prestressed Concrete Cylinder Pipe (PCCP), as any other pipe material, decays over time. The rate of decay is influenced by the quality of materials and workmanship used during manufacturing, construction methods, operational parameters and environmental conditions. PCCP pipe does not go from a perfect condition to failure instantly, but rather it is a deterioration or aging process that can be measured and tracked with sonic/ultrasonic nondestructive testing. Sonic/ultrasonic testing provides a definitive insight into the structural condition of every pipe in a pipeline. The detected pipe anomalies range from minor deterioration that does not significantly affect the performance of the pipe to conditions that indicate the pipe is in a severely deteriorated condition.

The testing results are repeatable over time. A subsequent sonic/ultrasonic survey provides the data needed to develop a pipe decay curve vs. time plot.



Periodic sonic/ultrasonic testing provides the data needed to develop a pipe decay curve vs. time chart. *Image courtesy of J.W. Marshall & Associates.*

For many reasons, all pipe sections in a pipeline do not age and deteriorate at the same rate. By knowing the rate of deterioration of a pipe or a reach of pipe, the present and future pipe reliability can be determined. With this information, a utility can cost effectively plan for needed pipe repair or replacement instead of waiting and ultimately performing emergency repairs. Emergency repairs are difficult from an unanticipated cost stand point and the resulting service interruption. Defined pipe or pipeline sections that require repair or replacement can be planned and the expense can often be capitalized.