http://dx.doi.org/10.5991/OPF.2013.39.0044

John Marshall is president of J.W. Marshall and Associates, Abingdon, Md. Paul S. Fisk is president of NDT Corp. (www.ndtcorporation.com), Sterling, Mass.

Sonic/Ultrasonic Testing Provides Reliable Condition Assessment

Nondestructive sonic/ultrasonic testing has been used to evaluate concrete properties for more than 60 years and to assess the structural condition of prestressed concrete cylinder pipe cores and coatings for more than 20 years.

BY JOHN MARSHALL AND PAUL S. FISK

PRESTRESSED CONCRETE cylinder pipe (PCCP) is a complex composite structure. For such pipe to function properly, all structural elements must perform as intended. Failure of any element—such as a reduction in concrete core strength, delamination between composite layers, and microcracking or core cracking—indicates the pipe section isn't functioning as intended and structural integrity is compromised. Sonic/ultrasonic testing can be used to evaluate these elements.

Many factors alone or in combination can shorten PCCP service life, including

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

Sonic/ultrasonic testing also can monitor the PCCP aging process. This allows personnel to estimate a pipe's remaining useful service life and effectively manage the pipeline.

HOW SONIC/ULTRASONIC TESTING WORKS

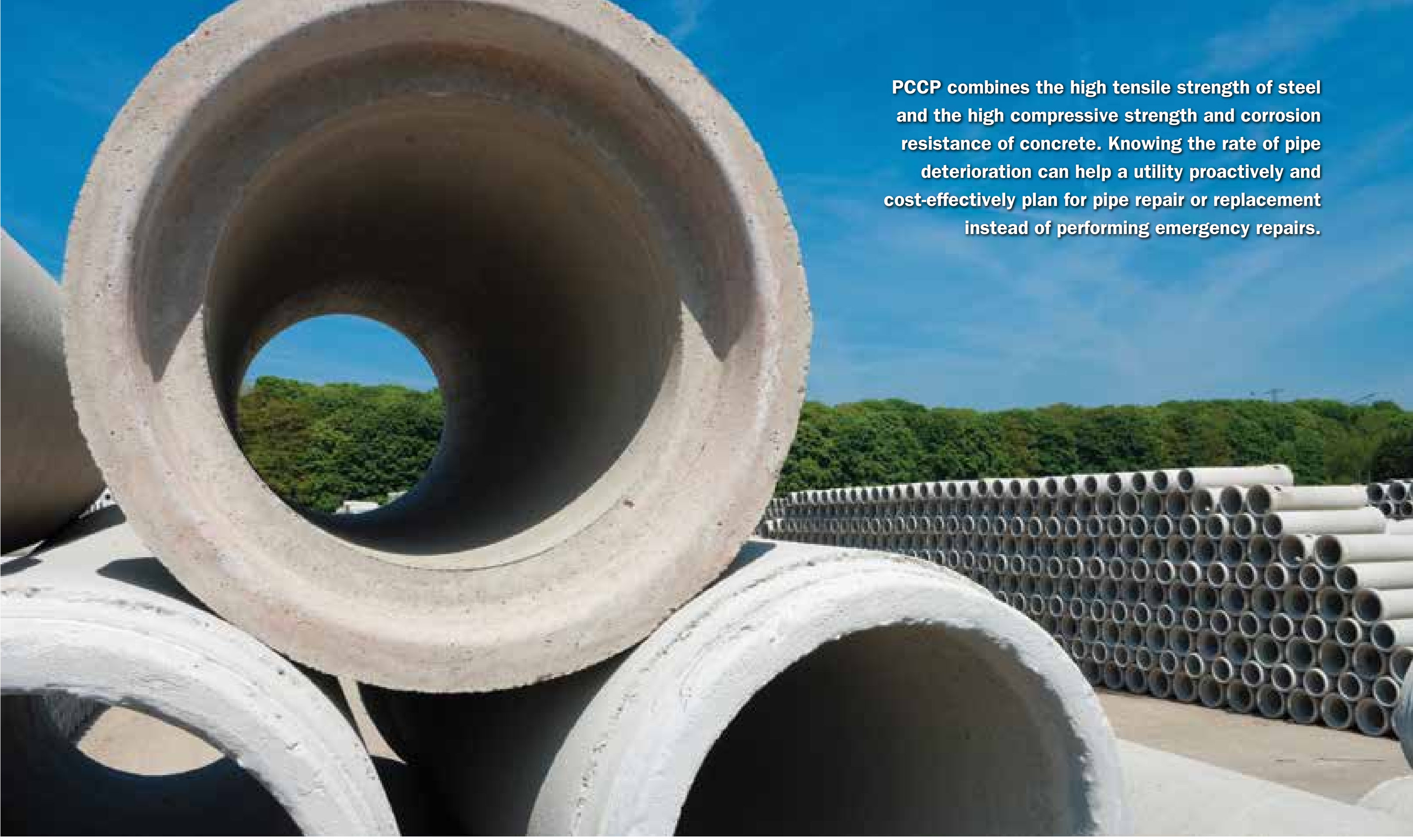
Measurements are made by creating an acoustic stress wave in the sonic/ultrasonic frequency band with an impact and measuring the transmission velocity of compressional and shear waves and resonance (impact echo) from the pipe's exterior surface or from delaminations within the pipe. Transmission velocity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

Such testing provides information to determine if a pipe is functioning as designed or the pipe is deteriorating. Signs of deterioration include wire breaks, loss of prestressing, overloading, or coating deterioration.

Wire Breaks. Tests on an out-of-service 60-in.-diameter PCCP demonstrated the effectiveness of sonic/ultrasonic measurements in detecting cut or broken prestressing wires. With cuts in 11, five, and six wires in different locations, sonic/ultrasonic measurements were made along a continuous line of coverage across all three wire-cut locations. As shown in the photo at bottom right, the mortar coating on both sides of the cut wires was well bonded to the prestressing wires.

Sonic/ultrasonic test results indicated loss of full-thickness resonant frequencies for data acquired directly over cut wires. Measurements in areas where wires weren't cut showed no change in velocity or resonant frequency data, indicating the effect of the broken wires was confined to cut-wire areas. These measurements were repeated annually for six years with no significant changes in velocity values or resonant frequency, indicating the mortar coating and adjacent uncut wires were keeping the prestress wires in tension, outside the wire cut areas.

Test results were confirmed in the field. An electromagnetic and sonic/ultrasonic survey inspection conducted on a 66-in. PCCP indicated broken



PCCP combines the high tensile strength of steel and the high compressive strength and corrosion resistance of concrete. Knowing the rate of pipe deterioration can help a utility proactively and cost-effectively plan for pipe repair or replacement instead of performing emergency repairs.

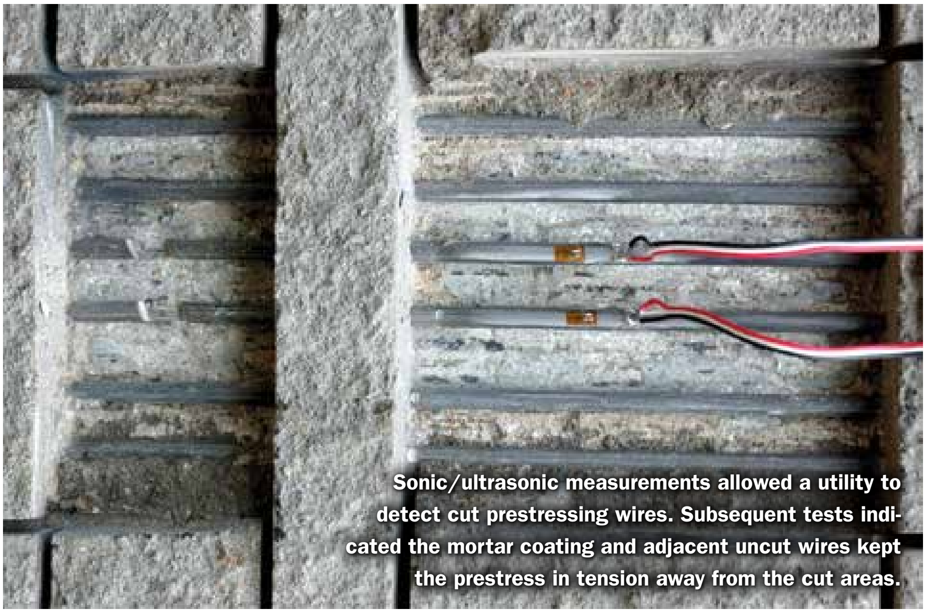
wires. Excavation and destructive testing showed the presence of the broken wires, which were located beneath a gouge in the coating that occurred during pipe installation 40 years ago. There was no wire corrosion or signs of coating delamination outside the gouged area.

The sonic/ultrasonic testing indicated the coating wasn't delaminated, and the concrete's strength hadn't been reduced. Based on a finite element analysis and the results of the sonic/ultrasonic testing, no delaminations or microcracking should occur.

Sonic/ultrasonic testing at another pipe location indicated a delamination at the pipe's spigot end. The prestressing wire in contact with the core showed significant corrosion, indicating the pipe was compromised. Above this position, corrosion wasn't present. This finding is significant, because most pipe ruptures at the utility had occurred at the spigot end at the location of the wire corrosion. Future sonic/ultrasonic surveys can document the corrosion's progression.

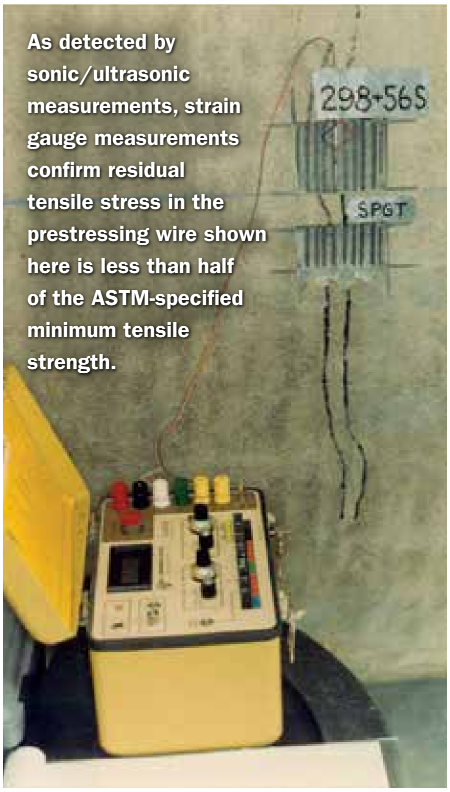
Loss of Prestressing. Field measurements made on 1,062 108-in.-diameter PCCPs for a major East Coast metropolitan water authority demonstrated the effectiveness of sonic/ultrasonic testing to identify pipe with wire prestressing loss. Testing indicated two pipes had a loss of full-thickness resonant frequencies, low velocity values, and poor signal attenuation. The combination of these sonic/ultrasonic signal characteristics indicated the pipes were substantially compromised. The pipes were excavated and destructively tested.

Visual inspection of the pipes' exteriors indicated a crack at the spring line of one pipe. Strain gauge measurements, as shown in the photo on page 18, indicated the residual tensile stress in the prestressing wire was 45.8 percent of the ASTM-specified minimum ultimate tensile strength, compared with the normal pipe manufacturer's wrapping stress of 75 percent. Subsequent pipe demolition revealed six splices in a half length of the



Sonic/ultrasonic measurements allowed a utility to detect cut prestressing wires. Subsequent tests indicated the mortar coating and adjacent uncut wires kept the prestress in tension away from the cut areas.

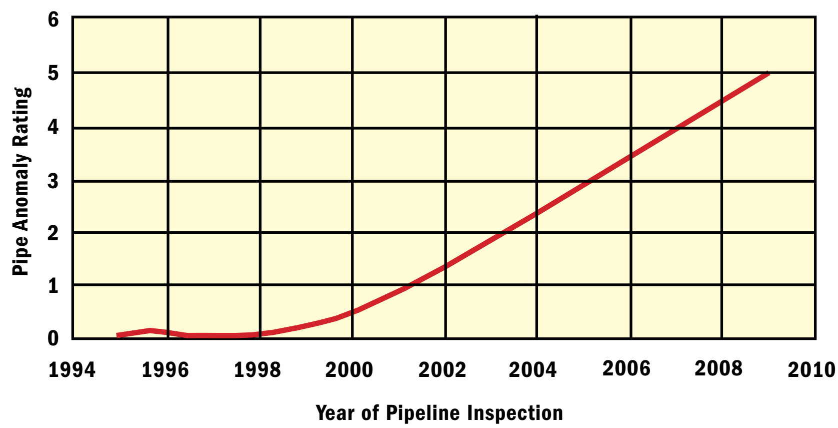
PHOTOGRAPH: LEWIS ENGINEERING AND CONSULTING (BOTTOM RIGHT)



As detected by sonic/ultrasonic measurements, strain gauge measurements confirm residual tensile stress in the prestressing wire shown here is less than half of the ASTM-specified minimum tensile strength.

PCCP Decay vs. Time Curve (Pipe D397)

Periodic sonic/ultrasonic testing provides the data needed to develop a pipe decay curve vs. time chart.



Source: J.W. Marshall and Associates

pipe, an unusually high number for PCCP and a possible reason for low tension in the prestressing.

Overloading. Pipe overloading conditions may occur because of poor bedding, surges, increased soil cover, or inadequate wire prestressing. Sonic/ultrasonic testing indicates these conditions by a loss of pipe thickness resonant frequencies for most, or the entire, pipe. However, velocity values will be within a normal range for PCCP. The results indicated the core concrete was microcracked but not at a level that had significantly affected core concrete strength.

Sonic/ultrasonic test results of a major western city's 60-in. main that failed because of a surge indicated similar results—loss of full-thickness resonant frequency values and normal velocity values for compression pipe. When pipe is significantly overloaded, core concrete strength is significantly compromised, indicating cracking and delamination between layers.

Testing of the previously mentioned 108-in. main indicated several consecutive pipe sections with loss of full-thickness resonant frequency values and normal velocity values for compression pipe. Project specifications required the rock to be excavated 2 ft below the bottom of the pipe and granular fill placed to the pipe spring line. Excavation of several sections indicated the pipes were resting on bedrock. To be bedded on a point load, the pipe was significantly underdesigned.

Deterioration Rate. The pipe characteristics—concrete strength, degree of microcracking, delamination, and inference of broken wires—that sonic/ultrasonic testing measures, along with measurement repeatability, make this technique an excellent tool to establish PCCP deterioration rates. Comparing current sonic/ultrasonic data with previously collected data determines the decay rate and characteristics of aging and weakening pipe.

Many pipes have defects that don't worsen with time and, therefore, aren't of great concern. However, pipes that become significantly worse over time will likely continue to decay at a high rate.

MANUFACTURE AND INSTALLATION

Many pipe defects occur during manufacture or installation. To understand these defects, an extensive sonic/ultrasonic testing program was conducted at a PCCP manufacturer's yard, including testing of lined and embedded cylinder PCCP during all construction phases. In addition, contractor-damaged pipe and pipe provided by a local utility were tested. The testing revealed manufacturing defects resulting from poor coating bond, wire splice where full prestress wasn't reestablished, low wire prestress, concrete core damage, and handling.

During testing, a pipe section was returned to the manufacturer because it was rejected by an installation inspector. Although the 96-in.-diameter pipe had been dropped by the contractor, there was no visible damage. Sonic/ultrasonic testing revealed the concrete core was severely cracked with delaminations of the mortar coating. With such undetected damage, this pipe would fail before reaching its design life expectancy.

PROACTIVE PCCP MANAGEMENT

As with any other pipe material, PCCP

PHOTOGRAPH: LEWIS ENGINEERING AND CONSULTING

For many reasons, all pipe sections in a pipeline don't age and deteriorate at the same rate.

DATA ANALYSIS

DETECT AND INTERPRET PIPE ANOMALIES

Sonic/ultrasonic testing can provide a tremendous amount of data about a pipe segment's structural condition. Accurately classifying pipe anomalies in terms of type and severity, sonic/ultrasonic testing provides consistent, accurate, repeatable data. By performing subsequent surveys and reducing the data using a classification system, pipe decay can be accurately monitored over time. A simplified approach was developed to display the reduced data visually.

Pipe anomalies are classified as follows:

- Occurring at pipe ends (represented as E)
- Occurring over a significant portion of the pipe (represented as OS)
- Isolated anomalies occurring in the pipe's center section (represented as C)
- Coating thickness reduction (represented as CR)

A 96-in. prestressed concrete cylinder pipe (PCCP) installed in 1987 was tested in 1995, 2000, and 2009 using the sonic/ultrasonic method. The accompanying table shows a small portion of the reduced testing data. As shown in the table, the pipe contained no anomalies from the time of installation to the testing conducted in 2000. By the 2009 inspection, however, there was substantial deterioration, with Pipes D396 and D398 showing significant deterioration at the pipe ends. These pipes weren't excavated; however, based on similar anomalies of excavated pipe, about 2 ft of wire were significantly corroded, and the mortar coating was separated from the core.

Although a large portion of Pipe D397 had significant deterioration, the pipe wasn't excavated; however, based on excavation of similarly rated pipe, 3–4 ft of wire were corroded near the bottom of the pipe with possible delamination of the coating. Pipes D393, D394, D395, D396, and D398 were losing prestressing, and pipe D397 had lost a significant amount of wire prestressing.

The analysis indicates that pipe sections are aging, with an accelerating rate of deterioration.

Test Results for a 96-in. PCCP Pipeline

Between 2000 and 2009, a 96-in. PCCP pipeline tested at 8-, 13-, and 22-year intervals using the sonic/ultrasonic method showed significant deterioration.

	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

Source: NDT Corp.

Pipe Anomalies	
Pipe end defects	E
Defects occurring over most of pipe	OS
Defects occurring outside pipe ends	C
Reduction of pipe thickness	CR

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

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 doesn't change from a perfect condition to instant failure; it experiences a deterioration or aging process that can be measured and tracked with sonic/ultrasonic nondestructive testing, which provides definitive insight into the structural condition of every pipe in a pipeline. Detected pipe anomalies range from minor deterioration that doesn't significantly affect pipe performance to conditions that cause severe deterioration. Because sonic/ultrasonic testing results are repeatable over time, subsequent sonic/ultrasonic survey results provide the data needed to develop a pipe decay curve over time, as shown in the figure on page 18.

For many reasons, all pipe sections in a pipeline don't age and deteriorate at the same rate. Knowing the rate of pipe deterioration can help you determine present and future pipe reliability. With this information, a utility can proactively and cost-effectively plan for pipe repair or replacement instead of performing emergency repairs, which lead to unanticipated costs and service interruptions. Defined pipe or pipeline sections requiring repair or replacement can be planned, and the expense often can be capitalized.