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An Update on Acoustic Emission Testing of PCCP

by

Will Worthington, P.E. Member ASCE [1]

I. Abstract

At the 1993 PCCP Pipe Users Forum in San Diego, the Bureau of Reclamation introduced the concept and development of Acoustic Emission Testing on Prestressed Concrete Cylinder Pipe (PCCP). Since 1993 a number of improvements have been incorporated into the technology as it is being applied commercially This paper will provide an update on the application of AET to PCCP pipelines.

II. Background

At the 1993 meeting of PCCP Pipe Users Forum in San Diego, the Bureau of Reclamation provided further information on their continuing investigation into the premature failure of Prestressed Concrete Cylinder Pipe (PCCP) in the Central Arizona Project. They reported on improved, very effective methods of refurbishing PCCP that was found to be in a state of distress. However in the absence of a reliable method of detecting areas of deterioration, the painful decision had been made to replace portions of the world's largest diameter PCCP.

In their search for a means of determining the condition of PCCP, Reclamation had perceived that acoustic emission technology might hold promise. (Worthington) Early experiments had demonstrated that the prestressing wire in PCCP emits a sharp sound when it breaks. Reclamation had detected and recorded these sounds using underwater microphones, or hydrophones, at a distance of 1,524 meters (5000 feet). Armed with this information, Reclamation was in the process of developing and installing an acoustic emission test (AET) system on the PCCP inverted siphon at the Agua Fria River in Arizona.

Early interest in AET stemmed from operational aspects of this technology as well as its technical potential. It was realized that it would not be sufficient to focus attention on a few pieces of empty PCCP in a laboratory environment. The pipe owner's problems are different. They face a pipeline which is buried, which is usually difficult to take out of service, and which is up to a hundred miles long. So a system that might look good to a scientist may not fill the bill for a pipeline owner. The owner needs a pipeline inspection method which:

1. Will Worthington, President, Pipeline Technologies, Inc. 1425 North Hayden Road, Scottsdale, AZ 85257

- is reliable
- is quick
- performs without taking the pipeline out of service
- performs without uncovering the pipeline
- will detect areas of distress early enough to permit refurbishment
- is cost-effective

Many technologies and methods which held promise of meeting several of these criteria but AET appeared to have the potential to meet all six.

III. Principles of Acoustic Emission Testing

Passive acoustic emission detection technology has been recently adapted to concrete pressure pipelines. This method of inspection is based on the acoustic emissions made by the prestressed reinforcing wire as it releases its energy.

Prestressed concrete pipe is reinforced by spirally wrapping high strength wire around a concrete cylinder. If the pipe is in a state of distress, the prestressing wire will be involved. When this occurs, the wire will break in a relatively brittle fashion, with an instant release of the tensile force up to 5,000 kg (11,000 pounds) in that strand of wire.

Much of this energy is in the form of sound energy which propagates through the pipe core and into the column of water within the pipe. The broken ends of the wire are immediately re-anchored in the protective mortar due to friction and the Poisson effect. If the deterioration continues, the protective mortar will be further compromised and the stored energy within the prestressing wire will be released in a series of discrete events. As more wires in the area of distress are involved, they too will break. The process of deterioration leading up to a corrosion-related failure takes several years to run its course, and it is a very noisy process.

Pipeline acoustic emission technology draws heavily from the field of anti-submarine warfare. In anti-submarine warfare and in pipeline testing, acoustic emissions of interest are detected by a series of hydrophones and screened for the known acoustic signatures that are emitted by an event of interest. The opening of a torpedo door is an event of interest to submariners. The release of energy by the prestressing steel is an event of interest to PCCP owners. These and most other events have unique acoustic properties which allow these events to be distinguished.

The precise identification of the arrival times of these signals at a series of hydrophones is used to locate the source of the events. Sound travels through water at a known and constant speed. That speed is approximately one mile per second, or about five times the velocity of sound in air at sea level. The time it takes for a sound to arrive at a hydrophone is directly related to the distance it travels. The greater the distance, the longer the time. Therefore, the physical location of a wire break can be determined by comparing the arrival times of that event at both hydrophones.

The figure below highlights the components of an acoustic emission detection system. The illustration simulates a wire break close to the left hydrophone. The sound from this event will be detected first at the left hydrophone and momentarily later at the right hydrophone. By comparing the difference in arrival times between the two hydrophones to millisecond accuracy, the location of the event can be determined.

IV. Early Experiments

In 1991, the U.S. Bureau of Reclamation performed the first experiments to establish the viability of using AET to identify and locate structural distress in PCCP. A single strand of prestressing wire was cut while a hydrophone one mile away monitored acoustic signals in the water in the pipeline. The sound of the breaking wire was distinctly identified. This opened the door to the adaption of AET to PCCP pipelines.

To avoid "reinventing the wheel", Reclamation actually worked with the U. S. Navy's Naval Research Laboratory (NRL) to assess the feasibility of the technology. NRL analyzed several sample acoustic signals and advised that AET is fully capable of doing what Reclamation was trying to do. NRL assisted in establishing parameters for a system to meet pipeline conditions.

Following further testing in 1991 and 1992, a system was developed and permanently installed on a 3.2 km (2-mile) inverted siphon in Arizona. That system consisted of 12 hydrophones inserted through valves added to the pipe at 305 meter intervals (1000-foot) for that purpose. All signals were transmitted real-time to a signal processor located on site. Signals were classified and localized for immediate use by the system operator.

Many important lessons were learned from this system. First, the quantity of data was surprisingly high. As a result, the condition of the pipeline began to come into focus within a few days. It did not require months of testing as had been anticipated. This is attributed to the relatively noisiness of the pipe deterioration process, and suggested that a permanently installed system may not be necessary. A portable system with an approximate test period of days or weeks was discussed. This, however, would require some method of replacing the buried cable in order to be practical. Another important lesson had to do with the sensor spacing interval. The hydrophones in this system were spaced at 305 meter (1000 foot) intervals. The analysis of signal detection indicated that this spacing was probably overly conservative, and that spacing greater than 305 meters (1000 feet) was justifiable based on the data gathered. (Reclamation)

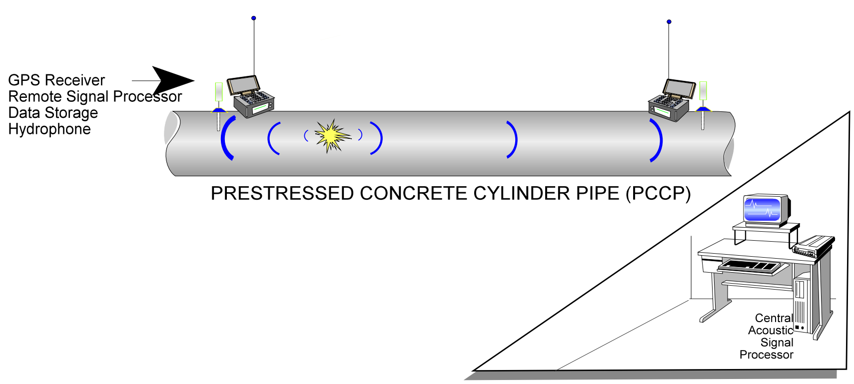
V. Current Acoustic Emission Test Equipment -

Systems have been developed commercially which take advantage of these lessons learned. One acoustic emission detection system (See Figure) in commercial use new is the proprietary AH-1 Pipeline Test System. This system consists of:

- A series of two or more sensitive hydrophones are used to detect noise in the pipeline. These sensors are mounted on the end of a stainless steel shaft which is inserted into the pipeline through a series of seals and valves while the pipeline is in service at operating pressure. The hydrophones are usually installed in the pipeline through existing air valves after temporarily removing the air handling mechanism.

- Signals from these hydrophones are monitored by a small computer located close to the hydrophone. This battery-operated computer screens all acoustic activity against the acoustic signature of prestressing wire-related emissions. The computer records all signals matching the wire signal characteristics on data storage disks for later processing.

Autonomous Sensors for Pipeline Inspection
AH-1 System



- A third component

of the system, and the key to elimination of the cumbersome telemetry, is the global positioning system (GPS) antenna and processor which is incorporated into the acoustic system. This feature accomplishes two purposes. Primarily it serves as a very accurate clock. It determines the precise time of passage of the signal to an accuracy greater than a thousandth of a second. This precise time of passage is compared to the same information at adjacent hydrophones to determine the point of origin of the sound. Coincidentally it provides the location of the hydrophone in latitude and longitude so that there is no ambiguity as to where a signal was detected.

VI. AET Performance to Date -

We have been involved in the analysis of acoustic data from ten different pipelines. In eight cases, the testing has confirmed that the PCCP is in good shape. In these instances, the results have proven useful to the pipe owners even though no bad pipe has been detected. For example, one pipe owner was faced with a decision as to the advisability of replacing a 20-year-old, 8 km (5 mile) long pipeline due to a road widening project. The pipeline in question was manufactured by now-defunct Interpace at a time when quality was a problem. AET testing showed this particular line was in good condition and not actively deteriorating. Based on the results of this testing, the line was left in place at a savings of approximately $6 million. This decision was based in large part on the confidence that pipe owner gained from spot checks using AET for which he paid less than $50k.

In two instances, our conclusion was that the pipe was in an advanced state of deterioration. Excavation for visual inspection of the pipe surface was recommended. It is worth noting that in both instances, the pipe had been tested by a visual interior inspection (with sounding) by experienced personnel. There was no indication of distress whatsoever. In both instances, the pipe had been evaluated using over-the-line potential methods, again with no indication of distress. In both instances, our recommendation was accepted and the pipe was excavated for visual inspection.

The distress in the 252-inch pipe was detected based on less than 20 hours of data. (Reclamation) Distress in the 72-inch pipe was based on 160 hours of data collected by a pair of hydrophones spaced at 590 meters (1940 feet). (Marshall)

Photo 1 - Reclamation's 6.4 meter (252-inch) PCCP Pipe Distress Detected Acoustically

Photo 2 - 1.8 meter (72-inch) PCCP Pipe Distress Detected Acoustically

VII. The Future -

We feel the future is bright for PCCP pipe owners, insofar as condition assessment and rehabilitation is concerned. Five years ago at the last meeting of the PCCP Users' Group, there was no proven technology available to give reliable condition assessment of PCCP lines. AET is available commercially now. We expect continued advances in the AET systems. Testing and research will further increase the confidence we can place in the results. As we continue to gain experience, we will become more efficient in its use. Additional technologies will also become practicable. Developments will continue in active acoustics - impact echo and ultra-sound systems. Remote field eddy current technology shows much promise. In some instances these technologies will compliment AET to give additional information. In some instances there will be systems that compete with AET.

Pipe owners by nature are conservative. In our discussions with pipe owners regarding the use of this technology, several thoughts are frequently expressed. First, they would like to see a long list of satisfied customers before signing up to try this technology. That was a tough nut to crack, getting the first commercial customer. The list may not be long now, but there is a list and it is growing, and they are well-satisfied.

A second concern is that the price seems too high and if they wait a few years it will come down. The development of this technology is not inexpensive. There has no research or development money available in the US to defray the development costs - not federal, not AWWA, not ASCE, not ACPPA, not SBIR. These costs must be recovered. It should be noted that both AWWA Research Foundation and ACPPA have undertaken studies to evaluate various technologies, and this is a step in the right direction. Clearly if all pipe owners take the position of waiting until there is a long list of customers, and until others have absorbed the costs of technology development, it will not happen. The future for AET and other technologies will be bleak. I am sure all of us involved in the development of systems aimed at pipeline condition assessment will agree on this point: We need your support, and we need the opportunity to demonstrate that AET works now for owners of PCCP.

There is a compelling analogy between what we do with AET and what a cardiologist does with the EKG - the electrocardiogram. Both entail the use of sensors placed on a pipe to measure and analyze acoustic data. Both give a condition assessment in a relatively short test period. I give my prognosis for the future of AET:

> *Within ten years the use of AET in the PCCP pipelines will be as commonplace as the use of the EKG in health care today.*

Demonstrations and refinements of this technology will develop the confidence and support of PCCP users in order for this to occur. AET will not be the only technology used in this role, but it will continue to evolve as a very important tool.

VIII. References

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