ACOUSTIC EMISSION TESTING
Theory

During its manufacture, PCCP is reinforced by spirally wrapping high strength steel wire around a concrete cylinder. Occasionally this wire starts to fail, and the PCCP begins to degrade. Eventually, the wire breaks and the stored energy within the prestressing wire is released.

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. If the deterioration persists, the prestressing wire continues to corrode, break and slip, releasing more energy in a series of discrete events that can be detected by an Acoustic Emission Testing (AET) system. The origin of acoustic events is located through the precise identification of the arrival times of these signals at a series of sensors. Sound travels through water at a known and constant speed of approximately 4,850 feet per second. The time it takes for a sound to arrive at a sensor is directly related to the distance it travels. Therefore, the physical location of a wire break can be determined by comparing the arrival times of that event at both sensors by using the equation shown below:

\[X_1 = \frac{[V(T_1-T_2) + D]}{2}\]

Where:
- \(X_1\) = Distance of acoustic event from Hydrophone #1
- \(V\) = Velocity of sound in water
- \(T_1\) = Time of arrival of acoustic signal at Hydrophone #1
- \(T_2\) = Time of arrival of acoustic signal at Hydrophone #2
- \(D\) = Distance between the two hydrophones
Application

Sensor Spacing

In general, cost effective execution of an AET monitoring program demands maximum spacing between sensor monitoring stations while ensuring all wire related events in the reach of pipe being monitored are 100% detectable and 100% localizable.

Sensor spacing is determined specifically for each project based on the pipeline being tested and the surrounding environment to ensure accurate results. PPIC uses a series of standards and years of experience to dictate the spacing of sensors. The AH-5 is extremely efficient at detecting any acoustic activity within the pipe, and facilitates sensor spacing of 500 to 3,000 feet.

Sensor spacing is a function of a number of factors including:
1. Characteristics of the sensor and the pre-amplifiers used
2. Characteristics of the signal processor
3. External noise levels
4. Pipe characteristics

PPIC is able to control items 1 and 2, and have developed systems that:

- Focus on the frequency range specific to wire break activity (the AH-5 can even distinguish between a calibration event and a wire-related event);
- Can eliminate external RF noise;
- Are extremely flexible in terms of placement and location along the pipe;
- Have virtually no internal systems noise, making the sensor unit extremely sensitive to external acoustic activity;
- Use systems that have an extremely high sample rate; and
- Utilize 16 bit data samples, which means that all the information is captured, across all the relevant frequency spectra.

To control for external noise levels, PPIC is aware of the fact that acoustic propagation within a pipeline is a function of a number of factors including: the quality of the water; the presence of organic material in the water or on the interior pipe surface; the presence of air pockets; the presence of entrained air in the water; flow noise; other background noise within the pipe; pumping noises in the pipe; and background noise outside the pipe, etc. PPIC controls for these external noise factors by conducting calibration tests as the units are installed.

Pipeline characteristics also impact sensor spacing. Smaller diameter PCCP pipe will attenuate an acoustic signal more than larger diameter pipe. Other factors that can cause signal attenuation include the vertical and horizontal design of the pipeline and the presence of internal pipeline features.

Knowledge of these characteristics allows PPIC to set the hydrophone and sensor unit to maximum sensitivity (so allowing increased sensor spacing) and to filter out extraneous ‘noise’. However, because of these variables, and as a verification of the designed spacing, PPIC’s field crews conduct calibration tests as the AET units are installed to ensure that monitoring stations are spaced appropriately.
Installation and Calibration

Proper installation of the equipment is essential. PPIC’s hydrophones can be installed through any one inch (or greater) tap. During installation, the hydrophone is connected to a stainless steel shaft. A temporary watertight seal is mounted atop an existing valve. The hydrophone is then pressed through the seal assembly. Once the valve is open, the hydrophone is further pressed until the tip nears the main water column. The acoustic signal is pre-amplified at the hydrophone, and from there the output signal is continuously transmitted by wire to the signal processor.

Once installed, PPIC will conduct a series of calibrations that demonstrate that the system is effectively monitoring the reach of pipe. The Project Manager, will be responsible both for assuring calibration quality and for reporting any significant issues that could impact the project to management and WaterOne.

As a quality control mechanism, PPIC will collect the data from the signal processing units manually for the first three to five days of the monitoring period, during which time it will optimize the units for the pipeline being monitored. At the conclusion of this period, PPIC’s signal processors will transmit the data to a nearby base station, which shall use wireless communications to upload it to PPIC’s offices for the balance of the monitoring period.

Through out the project, the equipment will be calibrated and adjusted as necessary to ensure the data collected is of the highest quality to give accurate analysis. The collected data are reviewed daily and any necessary adjustments to the systems are made immediately to ensure data quality. These adjustments can be performed remotely via wireless communication, or by a PPIC technician physically visiting the site and making the adjustments manually.

Monitoring Time

The monitoring time for this project will be defined.

Analysis

AET testing will detect active PCCP deterioration where the prestressing wires are breaking, or have broken and are slipping within the surrounding mortar. Acoustic testing, therefore, does not indicate directly the number of wires that are broken, but rather which areas are actively deteriorating.

The AH5 monitors the response of the hydrophones on a continuous basis and stores all data into a memory buffer. A sophisticated transient noise detection algorithm is used to determine when an "acoustic event" has taken place at the monitoring station. When an event is recorded, a GPS time stamp is attached. The arrival times of the acoustic events at various monitoring points are then used to determine the origin of the event along the length of the pipeline.

Because the systems are extremely sensitive, many acoustic events will be detected and logged. As a “Pre-Analysis” measure, the algorithm and appropriate filtering levels are manually set during the initial monitoring period to ensure optimal system sensitivity. For example small energy events that are not detected at multiple locations can be rejected. Each pipeline will have a characteristic level of background noise depending on many factors such as pipe diameter, internal conditions, environmental conditions, etc.

In its analysis of possible Wire Related Events (WREs), PPIC’s analysts consider that a WRE, unlike other noise factors that can be recorded in a pipeline, has the following characteristics:
• It has a sharp transient
• It has a broad band,
• A frequency up to 40kHz and above
• A signal length of 15 to 75 milliseconds.

Therefore, every recorded event is sorted and preliminarily scored by an analyst to determine if it is a possible wire related event (WRE). Once the data are sorted, all events that could be a possible WRE are further analyzed by:

• Listening to them audibly;
• Viewing the event’s amplitude and duration in a spectral view (plots the event by time on the X-axis and the frequency on the Y-axis);
• Viewing the frequency response in a waveform view (plotting the event by time on the X-axis and the magnitude or energy intensity on the Y-axis); and
• Comparing the event to a database of previously recorded signals.

All events classified as a WRE after this process are further reviewed by a Senior Data Analyst and then the Project Manager.

Methods for Distinguishing Wire Breaks from Other Noise

As stated above, there are four main ways that wire related events are distinguished from other acoustic events: listening to the sound of the event, detailed examination of the amplitude time response, the frequency response and comparison of the signal to a database of previously recorded events. In addition, the location where the event originates often times provides information about the nature of the signal.

Three examples of actual recorded data from AET monitoring are shown below to help visualize the difference between the various signals. These figures, recorded in the waveform view, and the spectral view, graphically display what a WRE looks like when analyzed.

Example of a High Energy Wire Related Event, believed to be an actual wire break or slip
The above illustrates that AET can distinguish wire related events from random traffic noise, mortar cracks or noise generated by debris in the pipeline. However, in practice, it is difficult to distinguish between a wire-slip and an initial wire-break as wire-slips can theoretically release the same amount of energy as an initial break.
Equipment

PPIC’s monitoring system consists of a series of individual units spread along the reach of pipeline. Each temporarily stationed, battery powered unit collects data from a sensor and transmits it to a nearby base station. The base station transmits the data to PPIC’s offices for analysis. Ideally, PPIC places a temporary solar panel near each unit to maintain a charge on the batteries.

As shown below, the monitoring system includes three different communication modules:

- Wireless communication between the AH-5 client (AET monitoring station) and the AH-5 server (base station). The client and server can be located up to 15 miles apart.
- Wireless communication between multiple AH-5 units and a base station.
- Internet communication between AH-5 server and PPIC’s offices.

The AH-5 units can be controlled and operated from PPIC’s offices. Only minimum manned attendance, during system setup and retrieval, is required.
The main components of the AH-5 system are:

Sensors

A series of two or more sensitive hydrophones are used to detect wire related events. PPIC field staff use rigorous and detailed procedures when assembling and installing the sensors. The sensors we use for our AET testing have been custom designed and manufactured to our strict specifications for the detection of acoustic signal frequencies that accompany PCCP deterioration. The hydrophones and their cables are the only components of the AH-5 system that are inserted into the pipeline through any 1 inch (or greater) tap.

PPIC uses two types of sensors to record acoustic activity. Typically very sensitive hydrophones, inserted into operating pipelines, have been used to detect and record these wire related events. However, recent advances in instrumentation and sensor technology have resulted in the use of non-intrusive, surface mounted accelerometers instead of hydrophones. The use of these sensors mounted on the surface of prestressed concrete pipe has negated the need to tap the pipelines to allow the insertion of hydrophones. Accelerometers also allow greater flexibility in selecting sensor spacing and virtually guarantee 100% coverage of the pipeline that is being monitored.

PPIC’s system of autonomous sensors has several advantages over array-based systems including:

1. The equipment is designed for one purpose: condition assessment of operational PCCP pipelines.
2. The acoustic monitoring system can be installed and utilized without any interruption to water delivery pressures.
3. Internal pipeline obstacles such as internal butterfly valves, T-junctions or Y-junctions do not compromise its use or installation.
4. The system’s use or installation is not compromised by horizontal or vertical bends in the pipeline.
5. There is no risk of the system disengaging and becoming entangled on internal pipeline features.
6. Sensor spacing is custom designed for each project, to ensure accurate results. Previous sensor spacing is not carried from one project to the next.
7. PPIC’s Surface Mounted Hydrophones are fixed in location. This gives PPIC the ability to localize events in a larger diameter pipe with a higher degree of accuracy than an array based system.

Signal Processor

Signals from the sensors are monitored by the second component, a small computer located close to the sensor. The signal processor installed in this portable computer...
receives the electronic signals and screens them against a series of criteria - some of which are established by the operator at the time of the testing. It samples the incoming signals from each sensor and records all signals matching the operator's criteria and transmits them to the Base Station for upload to PPIC offices.

**Precision Timing Device**

The third component of the AH-5 is the Global Positioning System (GPS) antenna and processor. The GPS provides the location of the sensor in latitude and longitude so that there is never any error in knowing where the instrument was located when the data was gathered. Most importantly, it serves as a very accurate clock. It determines the precise time of passage of the signal to the level of 1/1000th of a second. This event is then compared to the same information at adjacent sensors to determine the point of origin of the sound.

**Base Station**

The Base Station allows remote communications amongst AH-5 units and supports full wireless control and data management of AH-5 unit. This allows the AH-5 project team to log onto the internet in the office and log into the base station wherever it is located. The base station consists of:

- A PC unit that both controls the autonomous AH-5’s and stores the acquired data.
- A wireless communication module that simultaneously downloads data and uploads instructions to multiple AH-5 units. This also enables the project team to check the status of any autonomous AH-5 unit and make any control modifications necessary as demanded by real-time monitoring.
- An internet communication module that facilitates communication and enables monitoring from a remote office site.

These four components comprise an autonomous AH-5 unit. This system enables PPIC to provide continuous on-line assessment of the condition of prestressed wires, any ongoing wire-related events or other mechanisms that would adversely affect the structural integrity of the prestressed wires on the pipeline segments under inspection.