# Tucson Water's Strengthening Approach to Address Thrust Restraint for PCCP

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## 1. ABSTRACT

Since 1999, Tucson water has had an active PCCP asset management program utilizing inspection and advanced structural materials such as carbon fiber. The program strategy includes precision inspection methods which identify distressed pipe segments and pro-active rehabilitation of those segments. In January 2013, separation of several pipe segments located at bends in an 84-inch PCCP line was identified. The separation of the joints was due to combined loading issues at the bends, specifically inadequate thrust restraint. The pipe sections with inadequate thrust restraint were strengthened using carbon fiber primarily applied in the longitudinal direction in order to address the identified issues. The use of the trenchless repair method was favorable due to the difficulty of excavating in the distressed pipe region. The application of carbon fiber for this design condition was a significant advancement beyond typical CFRP rehabilitation which involves reinforcement primarily in the hoop direction. This paper will provide valuable information and insight into the use of CFRP to address thrust restraint.

## 2. BACKGROUND ON TUCSON WATER ASSET MANAGEMENT

Tucson Water currently serves approximately 710,000 customers with a water system consisting of 4,500 miles of underground pipelines. In 1999, Tucson Water experienced a catastrophic failure of a 96" Pre-stressed Concrete Cylinder Pipeline (PCCP) and a 72" Butterfly Valve (BFV). The 96" PCCP failure cost the City of Tucson over $5 million and a total of 12 homes were condemned. From 1999 to 2005, Tucson Water focused efforts on creating a Pipeline Protection Program, Corrosion Program, and procuring the necessary capital improvement funds to ensure safety and implementation of advanced technologies.

One of Tucson Water's first steps in implementing their asset management program was to create an inventory of all pipeline assets categorized by criticality for corrosion. This effort focused primarily on PCCP lines and critical foreign gas line crossings.

By 2005, several portions of the PCCP lines were being acoustically monitored with hydrophone arrays. The methodology at the time was that if there was no activity, the hydrophones were relocated. In 2006, Tucson utilized a customized Acoustic Monitoring system and installed Fiber Optic Cable in the PCCP lines. Specialized transient pressure sensors were also installed on each of the PCCP pipelines to capture all pipeline surges. The transient pressure sensor units perform well in capturing the events of water hammer and have served as an effective tool for Tucson in aligning documented wire breaks.

Tucson performed multiple tests on the PCCP lines and determined corrosion prevention was vital to the Pipeline Protection Program. An impressed cathodic protection (CP) system was designed and installed on 83% of all PCCP. The CP system was designed utilizing a low current requirement and narrow operational design criterion. Ground beds were designed close to each other to maintain consistent overlapping CP gradients and to prevent over-voltage potentials at rectifier/groundbed locations. Each site is monitored by a Remote Monitoring Unit equipped with a reference electrode and capable of measuring instant on/ off potentials to control CP levels. The importance of the designed CP system is to protect the pipelines from corrosion while avoiding the possibility of over-voltage, because it can lead to hydrogen embrittlement of the pre-stressing wires within the PCCP.

Also implemented was a Dynamic Risk Management program to actively monitor all PCCP lines. Advanced software documents all acoustic wire breaks, corrosion monitoring data, transient pressure sensor data, , , and, with the locations of the CP anode beds being known, creates a Direct Assessment tool for the analysis process.

To date, Tucson Water has performed multiple internal inspections and electromagnetic testing to ensure the integrity of the PCCP inventory. Pipeline inspections and repairs are predicated on the condition assessment and analysis of the electromagnetic testing, acoustic monitoring, visual inspections, and impact echo testing. This combination of asset management tools has created a comprehensive program mitigating risk for the citizens of Tucson.

Pipe repair and upgrades have been performed on diameters 54”, 78”, 84” and 96” PCCP. Tucson Water utilizes industry-wide services of professional engineering firms and local Job Order Contractors to fulfill the need for a pipe repair or modification.

## 3. RECENT PCCP EVENT – FAILURE AVOIDED

On August 21, 2012, Tucson Water was able to prevent a catastrophic failure on a 96” pipeline located in very close proximity to the first failure, which occurred in 1999. The acoustic monitoring system alerted Tucson’s Quality Control Manager of active wire breaks, which had the number of wire breaks increasing within a short amount of time. While the active wire breaks are common, the timing and frequency of the wire break events caused significant concern for Tucson Water. As previously highlighted, the last catastrophic failure cost the City over $5 million in collateral damage. In addition, approximately 38 million gallons of water were lost into the Santa Cruz River within 90 minutes. With this history, it was quickly decided to shut down and isolate the 96" pipeline segment.

The result of this emergency action plan was that the status of 96" pipe number 082 was elevated to "imminent failure" and immediate action was taken to address the distressed pipe segment. While the dewatering process took place, the pipe was also being excavated in order to repair by external post- tensioning. However, it was determined that the pipe was too distressed to allow for external post tensioning to take place when inspections revealed the pipe had severe mortar delamination, severely corroded wires, a cracked outer core, a compromised steel cylinder and multiple longitudinal and circumferential cracks. With the approval of Tucson Water's Administration and Condition Assessment team, a notice to proceed for Carbon Fiber Rehabilitation design was given and the pipe segments were repaired.

## 4. TUCSON WATER'S HISTORY WITH CFRP LINING

Over the past decade, Tucson Water has utilized carbon fiber reinforced polymer composite (CFRP) lining systems as one of the structural repairs implemented to address distressed pipelines. The use of CFRP composites for pipeline rehabilitation involves the application of epoxy saturated sheets of carbon fiber and glass fiber composites to the inside or outside of the pipeline, applied in the orientation designated on project design drawings.

**Figure 1. Mechanical saturation of carbon fiber fabric prior to installation in the pipeline**

Unidirectional carbon fiber fabrics, as shown in Figure 1, are typically relied on for structural integrity, whereas glass fabrics typically serve as the electrical isolator layer (on projects involving metallic pipelines or in the end termination details for PCCP) to separate the carbon fibers from direct contact with any metallic substrate being rehabilitated. Once cured, these composite materials serve as the structural system and often are designed to take all structural loads without relying on the host pipe for structural integrity.

## 5. 84-INCH CAP WEST MAIN CABLE INSTALLATION DISCOVERY

In late 2012, Tucson also scheduled a planned outage of a 66” through 96” pipeline to install a newly designed acoustic monitoring system as an upgrade to current acoustic monitoring equipment. During internal visual inspections, Tucson Water crews identified a pipeline leak, shown in Figure 2. The leak was identified as water penetrating the pipe wall from the outside.


**Figure 2. Observed joint damage (Photo Credit: Hector Posada of Tucson Water)**

A more thorough investigation revealed full circumferential cracks, with longitudinal cracks in the vicinity of a manufactured blow-off. The Condition Assessment team concluded that more information was needed to perform a failure analysis. The project engineer, Simpson Gumpertz and Heger (SGH) found that within a pipeline span of approximately 200 linear feet, pipe segments from the original C-301 design were restrained improperly and the pipe was unable to restrain the thrust forces on two adjacent 45 degree bends. SGH was able to simulate the thrust concern at the failure on the upstream joint and additionally on the downstream joint.

A CFRP liner was selected specifically because it could be installed rapidly, allowing the pipe to be put back in service in a very short time. In this case, the implementation of the CFRP upgrade was completed on an emergency basis. The normal planning, notifications, and construction time that would have been needed for a routine replacement of the damaged pipe segment made the replacement option infeasible.

## 6. REHABILITATION OF THE 84-IN CAP WEST MAIN

After the CFRP option was selected, the contractor had to provide a full design and technical submittal within a short period of time, as construction activities were to commence immediately. Design of the CFRP system was to take into account the longitudinal weakness as the primary driver and as such the majority of the reinforcement would utilize CFRP placed in the longitudinal direction. A benefit of CFRP lining systems is that the use of unidirectional material allows for the design to be customized to resist specific loadings in each direction. Figure 3 below details the repair area.

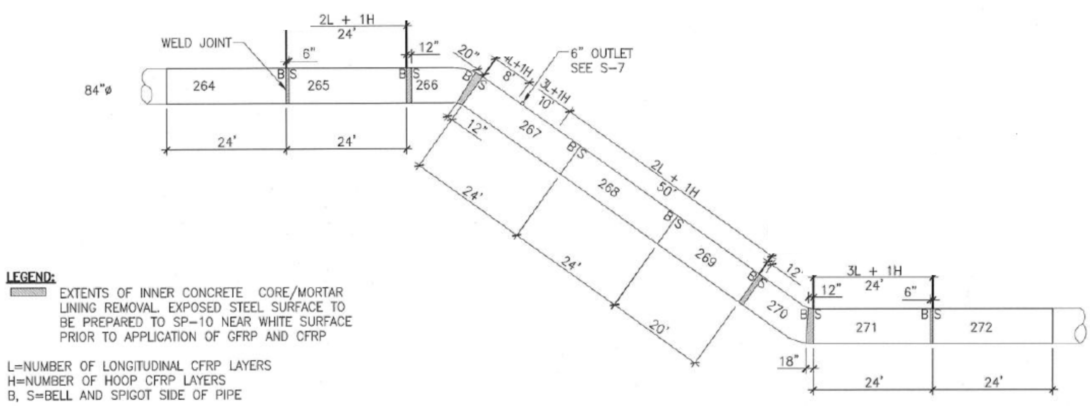


**Figure 3. Overall project scope**

As detailed above, a key aspect of this project was that the longitudinal deficiencies within the 84-inch pipeline segment were found to be caused by inadequately installed thrust restraint. The longitudinal forces acting on the pipeline were not properly resisted by thrust blocks and original pipe design, therefore the pipe segments developed circumferential cracks at the pipe joints where the pipe sections were pulled apart by the thrust forces.

Upon acceptance of the technical submittal, field operations commenced and the installation process was to take place over approximately two weeks. This included the time required to fully cure the CFRP system. Prior to beginning the CFRP liner installation, the leaks had to be addressed; for this repair the steel cylinder at each leak was welded, as shown in Figure 4. Because the leak in the pipeline occurred in the joint region where the CFRP lining system terminated, welding of the joint was required to ensure leak-tightness of the overall system.

**Figure 4. Welding of leaks in the joints prior to CFRP installation (Photo Credit: Hector Posada of Tucson Water)**

Following repair of the leaks, surface preparations took place over the approximately 165 linear foot repair area. Concrete surfaces were prepared to ICRI CSP3 profile and the steel in the joint regions was prepared to SP-10 near white metal blast specification. The surface preparation was verified through an adhesion test performed per ASTM D4541 on adjacent substrate. The minimum requirement for the adhesion test was a value of 200 psi, however values achieved were greater than 400 psi.

After the surface preparation was complete, the next step was to install specialized scaffolding within the pipe so that all surfaces could be accessed for installation of the longitudinal and hoop- direction CFRP. For the Tucson Water project there were some unique installation aspects, given that a considerable amount of the design included longitudinally oriented fiber.

Figure 5 shows the scaffolding in place as a layer of epoxy is being applied. The first material to be installed as part of the CFRP system is a prime coat of epoxy followed by a layer of thickened epoxy, which is also depicted in Figure 5. Figure 6 shows the Tucson Water pipe following installation of the CFRP system.

**Figure 5. Installation of initial layer of thickened epoxy prior to installation of CFRP (Photo Credit: Hector Posada of Tucson Water)**

**Figure 6. Completed CFRP lining (Photo Credit: Hector Posada of Tucson Water)**

Immediately following application of the thickened epoxy, the first layer of longitudinal CFRP was installed. The design varied, depending on the region within the pipeline, between a nominal thickness 0.24in and 0.5in with the majority of the reinforcement in the longitudinal direction and a minimal amount of reinforcement in the hoop direction.

Given the weakened joints where the leaks occurred in the pipe, the joint repair, especially end termination details, received focused attention during the design and implementation phases. As shown in Figure 7, below, the end detail provides a specially designed leak-tight connection through a tie-in with the steel cylinder.

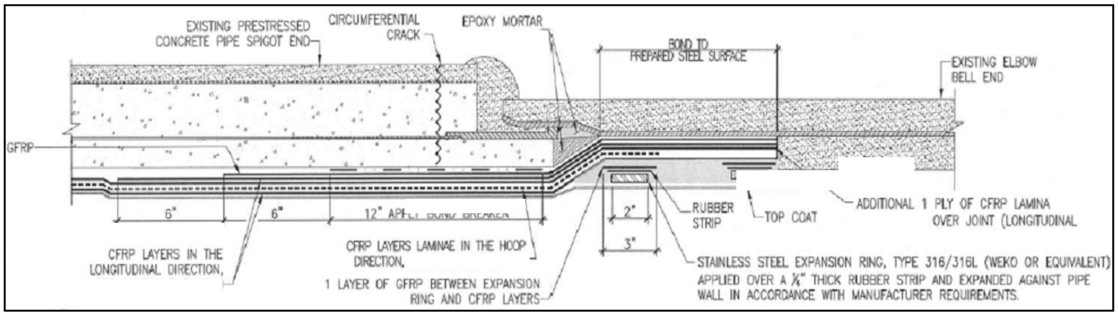


**Figure 7. End termination Detailing**

The finished end detail is shown below in Figure 8. The objectives accomplished by the CFRP liner and end detail design were as follows:

1. Capacity for movement of the pipe segments.
2. Water tight seal at the steel cylinder.
3. Longitudinal strength at the joint region to provide resistance to thrust loads.

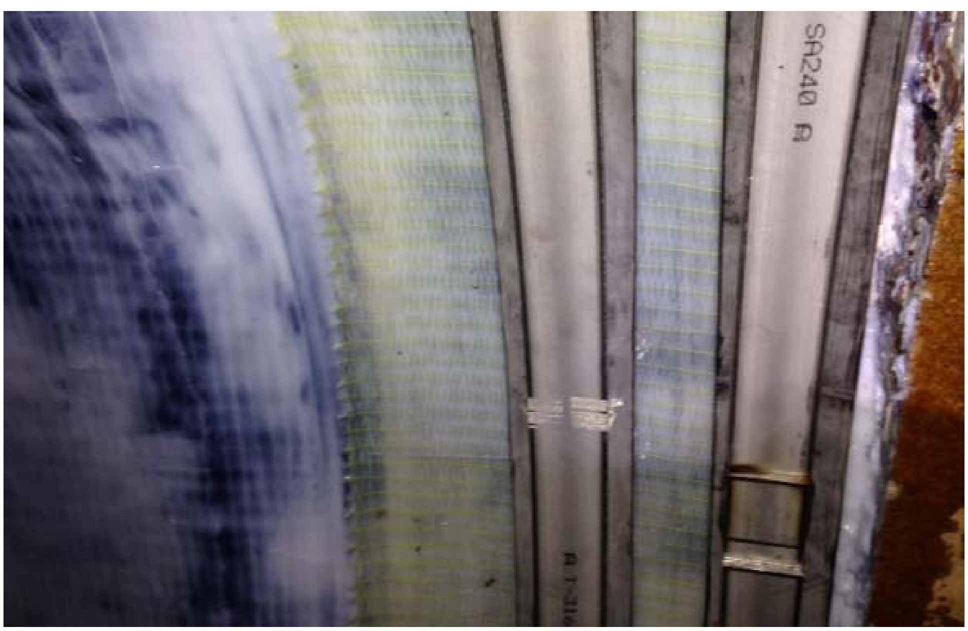


**Figure 8. End termination Detailing**

After the CFRP was fully cured, Tucson Water re-installed the fiber optic cable in the repair region. Figure 9, below, shows the cable installation taking place. The fiber optic cable in this region of the pipe is critical for monitoring the condition of the pipeline and ensuring system integrity between manned entry inspections of the system.

**Figure 9. Re-installation of acoustic fiber optic cable after rehabilitation work was complete (Photo Credit: Hector Posada of Tucson Water)**

## 7. CONCLUSION

Since the pipe failure event in 1999, Tucson Water has proactively addressed its PCCP system utilizing a comprehensive asset management program. The Tucson Water approach combines technologies and human expertise, creating an effective program with a documented success of preventing pipeline failures. The combination of the condition assessment program along with proven sectional repair materials and methods, such as CFRP, assisted in avoiding a catastrophic failure in the CAP 84-inch pipeline. CFRP proved to be an appropriate solution for a unique design condition, strengthening pipes or pipe segments which are distressed in the longitudinal direction due to thrust loads.