# Transitioning from Leak Detection to Leak Prevention: Proactive Repair of Steel Pipelines Using Fiber Reinforced Polymer (FRP) Composites

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## Abstract

Steel pipelines are the one of the most economic and safe transport systems for water, and are often our population centers' only means of receiving goods which are vital to day-to-day existence. As a means of long-distance transport, pipelines have to fulfill high demands of safety, and reliability. Most metallic pipelines, regardless of what they transport, are designed with a typical life span of 25 - 50 years. When they begin to fail, the pipelines slowly form leaks at construction joints, corroded areas and small structural cracks. These leaks can gradually progress to a catastrophic failure if gone undetected or can result in substantial water loss over extended periods of time. Pipeline leak detection systems (LDS) are beneficial because they can enhance productivity and system reliability by means of reduced downtime and reduced inspection time through pinpointing and localizing the leak locations. LDS Systems are therefore an important aspect of pipeline technology that are primarily used to assist Pipeline Owners in detecting leaks. But what happens after leaks have been detected in steel pipelines and require immediate repair?

This paper will present the importance of the correlation between efficient leak detection and pipeline repair. The general guidelines for the proper design and installation of fiber wrap strengthening systems for steel pipelines will also be presented. Discussion will center upon case histories and best practices to avoid over or under-designing the retrofit, and how to best implement the proper installation of

these CFRP systems. The case studies will be explored in detail to evaluate the performance of past and present designs, both for municipal and industrial clients.

## Introduction

Replacement of leaking and deficient steel pipelines can not only be costly, but time consuming as well. In many instances, pressure pipes in need of immediate repairs can ill-afford to be shut down for extended time periods. Through the widespread use of pipeline monitoring and assessment, pipeline systems are now often able to be repaired or replaced prior to catastrophic failure. One pipe repair method is application of Carbon Fiber Reinforced Polymer (CFRP) to the inside or outside of a pipe structure. Despite much advancement in structural and durability testing of CFRPs over the past 20 years, the design and application of fiber wrap in pressure pipelines is and will continue to be on a case-by-case basis with many variables determining exact design. As these pipelines are the "backbone" of so many communities, the importance of the proper design and implementation of fiber wrap systems is paramount.

CFRP liners have been used for the full structural repair, strengthening and retrofit of steel pipelines along with reinforced concrete and prestressed concrete cylinder pipelines. The main users of these pipeline structures are municipal water districts, power plants, and industrial facilities. The patented repair process is trenchless when providing internal repair and has been successfully utilized worldwide for more than a decade to rehabilitate many miles of pipelines ranging in diameters of 36-inch through 201-inch. Pipeline retrofits can also be performed externally on any diameter pipeline without requiring dewatering of the line.

Many factors are considered before deciding whether to repair or replace a pipeline. First, inspection of the pipeline must determine the structural condition of the pipe, then an assessment is performed to interpret the extent of the damage and finally a decision is made regarding the need to take action based on pre-determined criteria. Due to the challenges with increasing degradation, corrosion and other environmental damage to infrastructure, it is critical that pipelines are properly inspected and maintained to avoid rupture. Ruptures can be catastrophic, leading to explosions, craters, floods, severe damage to surrounding structures, and human lives may be threatened. Timely and accurate analysis of pipelines is of utmost importance. If a pipeline is deemed to be structurally deficient and chosen to be repaired, the proper design and installation guidelines for retrofit should be followed to ensure the performance of the pipeline.

## Leak Detection to Leak Prevention

Leak detection in pipelines is vital in preventing catastrophic failures from occurring. There are a limited number of leak detection methods to determine if any leaks exist or are starting to form in pipeline infrastructure. Methods used to detect product leaks along a pipeline can be divided into two categories, externally based (direct) or internally based (inferential). Externally based methods detect leaking product outside the pipeline and include traditional procedures such as right-of-way inspection by line patrols. Internally based methods, also known as computational pipeline monitoring (CPM), use instruments to monitor internal pipeline parameters (i.e., pressure, flow, temperature, etc.), which are inputs for inferring a product release by manual or electronic computation. One common leak detection method is acoustic technologies which detect changes in the acoustic characteristics within a pipeline in close proximity to a leak. Another common leak detection method is the correlator technology, which measures difference in travel time for leak noise to reach sensors placed on different locations on the pipe. The correlator technology can also be used to measure the average wall thickness of metallic pipelines, thereby allowing for thinned wall sections to be found prior to leaks occurring in the pipeline. The method of leak detection selected for a pipeline is dependent on a variety of factors including pipeline characteristics, product characteristics, instrumentation and communications capabilities, and economics. Pipeline systems vary widely in their physical characteristics and operational functions, and no one external or internal method is universally applicable or possesses all the features and functionality required for perfect leak detection performance.

Once leaks are detected in pipelines, leaks or dangerously thin wall sections must be mitigated through remedial measures. Fiber wrap systems have proven to be an effective method of leak repair and structural strengthening of pipelines for over 20 years. Pipelines may be wrapped with fiber wrap composites internally or externally depending on the application. However, fiber wrap is still a relatively new technology and must be properly designed and installed to provide an effective repair and a long design life for the pipe.

**Proper Design Guidelines**

When designing a fiber wrap system, it's important to understand that each application is unique and requires individual analysis to determine the general feasibility of its use. The external loads, internal pressures, and specified load and force reduction factors for each pipeline must be considered before designing the fiber wrap system. Design procedures are based on the completed structural testing in addition to available design guidelines and criteria such as International Code Council Acceptance Criteria 125 (ICC AC 125), ICC Evaluation Service Report (ICC ESR), American National Standards Institute (ANSI)/American Water Works Association (AWWA) C304-99, and the manufacturer's design manual (if available).

Fiber wrap systems are linearly elastic to failure, whereas steel yields and plastically deforms to failure. It's important to consider the stiffness, strength, and strain compatibility of the fiber wrap system. The elastic modulus and strain limitations control the fiber wrap system's performance. Inside a pipeline, the fiber wrap liner acts as a barrier that controls the level of strain experienced by the pipeline, allowing it to perform within its elastic range to ensure the pipeline's long-term performance is maintained. AWWA recommended strain limitations are 50 percent and 75 percent of the steel yield point for operating and surge conditions respectively. Consequently, these limits result in low CFRP stresses, providing a factor of safety greater than 5 for the fiber wrap liner. These strain limitations allow the repaired pipeline to accommodate the standard operating and surge pressures per industry recommendations, but will also control short-term pressures caused by unforeseen rapid valve closures that result in transient pressures up to five times the operating conditions. Therefore, fiber wrap liner designs are based on strain compatibility between the liner and the pipeline. Controlling strain significantly increases long-term durability by ensuring the CFRP and host materials don't exceed the limits for stress, cracking, and creep or stress rupture.

AWWA Research Foundation (AWWARF) and U.S. Environmental Protection Agency (USEPA) are funding research being performed by the US Bureau of Reclamation on the use of CFRP for the structural renewal of PCCP. AWWARF Project No. 4114, *Fiber Rehabilitation of Prestressed Concrete Pipe*, is addressing CFRP material properties and installation issues, as well as taking an in depth look at design issues and long-term material durability. At the conclusion of the three-year study, an AWWARF report will be produced along with a USBR specification on CFRP rehabilitation. This document will be another tool that can be used as a basis for designing and installing CFRP systems for PCCP repair and renewal. These efforts will supplement current design methods and may also serve to initiate what will eventually result in the publication of an AWWA standard. New CFRP technology research and development will continue to yield more effective systems and economical solutions for the pipe industry.

**Proper Installation Guidelines**

The performance and long-term durability of any fiber wrap system inside pipelines depends heavily on the proper installation of the system. Proper installation of a fiber wrap system can be ensured by using experienced installers who have more than five years of underground infrastructure work experience and an equal amount of experience with fiber wrap applications at a minimum. The applicator should have written documentation from the materials manufacturer that they have been trained and certified to install the manufacturer's materials. The materials manufacturer and applicator should submit structural and durability testing results to ensure that the fiber wrap system being installed has gone through extensive testing. The minimum testing that should be performed for the CFRP materials includes full-scale external load testing and internal pressure testing of pipes repaired with the CFRP liner, environmental durability testing, biological growth-support potential testing, cavitation resistance testing, measurement of volatile organic compounds (VOCs) in resins and ultraviolet (UV) testing for external strengthening applications.

**Installation Process**

The wet lay-up carbon fiber wrap process is a method by which the dry fiber wrap fabric is saturated in the field with epoxy resin then applied internally or externally to full sections of the structurally deficient pipe. The process for installing the fiber wrap on the inside of a pipeline is as follows:

1. Before commencing repairs, assess the host pipe's condition, set up safety and emergency plans, dewater the pipeline, check for hazardous gases, and set up ventilation and dehumidification systems.
2. In Pre-stressed Concrete Cylinder Pipe (PCCP) lines, use a high-pressure hydroblasting unit to remove the laitance (minimum amplitude of 1/16-in.) and expose the aggregate of the concrete from the inner core surface. In steel pipelines, the cement-mortar lining or any other type of internal lining should be removed first, followed by a further abrasive treatment of the pipe to white steel. After the surface is properly prepared and the walls have dried, additional repairs to the interior pipe surface can be conducted if necessary.
3. In preparation for the fiber saturation process, epoxy resins are mixed on-site. A specifically designed saturator is used to properly saturate measured lengths of 2-ft. wide dry carbon fiber fabric. When saturation is complete, the wet carbon fiber wrap must be applied within the working window of the resin system, which is typically between three to four hours depending on ambient conditions.
4. The surface is primed with thickened epoxy resin for application of the layers of the fiber wrap system.
5. The saturated rolls of fiber wrap are applied to the pipe wall. When the fiber wrap system is applied in the circumferential direction, the pipe is strengthened for hoop stress. When the fiber wrap system is applied in the longitudinal direction, some level of resistance to bending moments is accomplished.
6. A final topcoat of thickened epoxy resin further protects the fiber wrap system layers.

The finished system is typically less than ½-in. thick, thereby providing minimal change to the pipeline's internal pipe diameter. In some cases, when properly installed, the smooth and hardened surface of the fiber wrap system has been shown to increase flow capacity due to improved flow characteristics. The fiber wrap system also can be used to upgrade the internal pressure capacity of the pipeline, allowing the pipeline to be operated at higher pressures.

## Case Histories

Case histories demonstrate that when the fiber wrap system is designed and installed properly, it provides a long-term durable repair solution for a variety of different pipelines saving time and money, eliminating the need for large open-trench repair projects and reducing shut down time. The following are case histories using the

Tyfo® Fibrwrap® Systems for repair of steel pipelines (Fyfe Co. LLC is the manufacturer of these fiber wrap systems, and Fibrwrap Construction is a certified applicator of these fiber wrap systems).

## Conduit 94 – Denver, CO

In February 2008, Denver Water experienced a catastrophic failure in a 66-in. diameter section of steel pipe in Conduit 94 because of a pump failure as shown in Figure 1.

**Figure 1. Failed pipeline segment for Denver Water (EPA 2009)**

The failed section, located near an elbow where the steel pipe transitioned to PCCP, was replaced on an emergency basis with 40 ft of new cement–mortar-lined steel pipe that was procured from the inventory of a local steel pipe manufacturer. The two new sections were 0.307-in. and 0.375-in. thick, which didn't meet the Denver Water Board's specified factor of safety of 2 for the pipeline's design working pressure of 225 psi and surge pressure of 90 psi (Gedalia et al, 2010). Due to the location of the line 15 ft directly underneath the highway, CFRP repair was the only available option to upgrade the pipe. CFRP design considered safety factors for long-term load, short-term load, core crushing, and radial tensile strength. The cement–mortar lining was removed, and one longitudinal layer of glass fiber served as a dielectric barrier in order to prevent galvanic corrosion from occurring between the steel and carbon fiber because carbon is conductive. After the installation of the glass layers, the necessary number or layers of carbon fiber fabric were applied in the hoop direction in order to provide the required structural strengthening, as shown in Figure 2. The project was completed in a week during a scheduled maintenance shutdown.

**Figure 2. Interior of Denver Water Steel Pipe**

**Dominion Pipe – Yorktown, VA**

The 120" diameter steel pipe at this power plant was severely rusted due to the corrosive environment. A repair solution was needed that could withstand the harsh environment and be installed with minimal shut down time at the plant. A repair solution was designed using the Tyfo® Fibrwrap® System. One layer of the Tyfo® SEH glass composite system was installed longitudinally in the pipe. The glass composite provided strength in the longitudinal direction and also acted as a dielectric barrier between the steel and the carbon composite. This was followed by the necessary number or layers of the Tyfo® SCH carbon composite system in the circumferential direction. A coating of Tyfo® PWC was provided, as shown in Figure 3 as a durability coating and to allow for ease of future inspection.

Small crews certified to work in confined spaces installed the composite materials during a regularly scheduled shut down widow. A unique scaffolding system was designed to allow access to all sides of the pipe at one time. This ensured that the circumferential layer of the composite could be applied continuously around the pipe. The FRP composite solution to this pipe deterioration provided a quick repair technique to repair the deteriorated steel. There was minimal impact on the power plant operations and the solution has held up well in this aggressive environment.

**Figure 3. Interior View of Dominion Pipe**

## Conclusion

With the pipeline infrastructure aging, leak detection and prevention is becoming more and more important with time. With the increasing widespread use of fiber wrap, it is becoming more and more important strict quality control tight experience requirements are upheld in order to ensure that only proper materials are used and the CFRP liners are appropriately installed. In addition to ensuring proper materials, the existing standards for having trained and certified applicators should be strictly enforced in order to ensure proper installation and achieve the clearly stated design goals. Having experienced applicators with good workmanship cannot be disregarded as proper preparation and installation practices are important to avoid poor installations and catastrophic failures. Proper design guidelines, installation process, and the importance of applying these correct standards are all critical factors to consider for implementing effective carbon fiber repairs of pressure pipelines. Meeting the guidelines and criteria for the design and application, along with the ongoing research, ensures that the integrity of fiber wrap for retrofitting pipelines is maintained and improved upon.

## References

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