North American Society for Trenchless Technology (NASTT)
NASTT's 2014 No-Dig Show

Orlando, Florida
April 13-17, 2014

Miami Thrice; Lanzo, HJ3, and Carbon Fiber combine to preempt Catastrophic Line Breaks
Emergency Repair of Miami-Dade 54-inch and 48-inch PCCP for Drinking Water Using Carbon Fiber Reinforced Polymer (CFRP)

Olley Scholer, HJ3 Composite Technologies, Tucson, AZ 85705
Fred Tingberg, Lanzo Trenchless Technologies, Deerfield Beach, FL 33441

ABSTRACT

One of the more compelling stories being told within today's rehabilitation framework is that of how we are dealing with our aging Potable Water Infrastructure. The existence of deteriorated Large Diameter Pre-stressed Cylinder pipes (PCCP) in water transmission lines throughout the United States represents a liability shared by many municipalities. A vast inventory of late 1970's and early 1980's pipe are suspect due to corrosion and pre-stressing wire breaks. Our most prolific water authorities and municipalities have entered into a race against time to prevent catastrophic failure and shutdown from occurring in these water transmission lines. A path being followed is to first perform a condition assessment, and then to prioritize a repair schedule for deteriorated pipe. Since the 1960's, Fiber Reinforced Polymer (FRP) and Carbon Fiber Reinforced Polymer (CFRP) systems have increasingly become a reliable technology utilized for internal and external rehabilitation of PCCP and Reinforced Concrete Pipe (RCP). The use of CFRP has proven beneficial to the drinking water industry due to the fact that it can be field applied, avoiding the need for expensive and disruptive excavations. The integrity of CFRP repairs for drinking water pipe relies on: an accurate condition assessment of the host pipe, a transfer of the assessment and design information from the owner to a qualified engineer, a specification that requires qualified and experienced CFRP manufacturers, designers, installers, and inspectors. This paper shall present two separate projects performed for Miami Dade WASD where one such 54-inch and a 48-inch Lock Joint Cylinder pipe system were first non-destructively identified as being defective, then rehabilitated using the HJ3 manufactured CFRP repair system installed by Lanzo Trenchless Technologies.

INTRODUCTION

Of the 18,000 miles of pre-stressed concrete cylinder pipe (PCCP) within the drinking water transmission infrastructure laid between 1945 and 1996 in the U.S., almost half, or 8,600 miles of pipe, is considered to be end-of-life infrastructure, awaiting funding for replacement[1]. The American Society of Civil Engineers (ASCE) gave the United States a grade of D for its drinking water infrastructure, partially due to the 240,000 water main breaks that occur annually (approximately 657 per day) across the country, at an annual repair cost of $42 billion. The Environmental Protection Agency estimates the federal government must spend $384 billion to replace and repair all aging drinking water infrastructure over the next 20 years. Taking into consideration population growth, the American Water Works Association (AWWA) estimates the total Federal, State and private industry costs to exceed $1 trillion over the next 25 years for drinking water pipeline repair/replacements[2].

Absent funding for replacement, viable solutions are needed for extending the life of the nation's large-diameter, PCCP and Reinforced Concrete Pipe (RCP) drinking water infrastructure. Replacement is costly, and there is a spending gap between the $1 trillion required for repair/replacement and the money available over the next two decades. One solution, dating back to the late 1960's, involves in-place repairs for concrete pipe. Patent # 3,424,203 was filed in 1969 by D. Rubenstein and relates to efficient methods of repair for cracked, concrete pipelines. Repairs are made from inside the large diameter pipe by laminating polymeric resin composition-filler-fiber reinforcements into and onto the concrete body of the pipe. This process does not require excavation and is performed at a fraction of the cost to replace said pipe.

HJ3 Composite Technologies of Tucson, AZ, an innovative cleantech company, offers FRP systems for the repair and reinforcement of steel and concrete infrastructure. HJ3's FRP systems are supported by 25 years of large scale testing and include repair systems that have been used on numerous underground pipe repair applications since 2002. HJ3 and certified HJ3 CarbonSeal installer Lanzo Trenchless Technologies, have worked together in the Miami-Fort Lauderdale market to repair many of the leaking water pipelines with HJ3's CarbonSeal underground pipe repair system. The state of Florida alone requires $12.8 billion for drinking water infrastructure repair and $19.6 billion for wastewater infrastructure over the next 20 years, according to the ASCE[3]. HJ3's CarbonSeal carbon fiber repair systems offer water transmission pipeline owners like the Miami-Dade Water and Sewer Authority (MDWSAD) an alternative to replacement with 60-90% savings per repair, while extending the life of the structure for 50 years. Furthermore, HJ3's systems have been approved per ANSI/NSF-61 standards for potable drinking water.

PRE-QUALIFICATION REQUIREMENTS

Realizing the extent and critical nature of the repairs required, many of which are deemed emergency repairs, Miami Dade County embarked on the Miscellaneous Construction Contracts Program (MCC) where qualified contractors could be identified and established for participation in a more informal Bid Procedure than the typical Contract Cycle which could last months prior to actual work being performed. Having a sub pool of pre-approved and pre-qualified contractors capable of installing approved materials, using verified methods would shorten lead times and make mobilization onto respective jobsites virtually immediate, saving time and resources. The requirement for immediate mobilization was created allowing the MDWASD Director to declare the need for Emergency Construction Services in anticipation of the growing number of "imminent failure" sites being documented by the Condition Assessment subcontractor.

The MDWSAD further required that Carbon Fiber Reinforced Polymer (CFRP) manufacturers and installers both be pre-qualified to perform the rehabilitation work allowing them to provide a rapid response to the emergency repair. The CFRP certified installer (Lanzo) provided the documentation and client references required to demonstrate the following: 1) they are a registered Miami-Dade vendor, 2) written documentation showing the successful installation of the CFRP system for the rehabilitation of at least five independent pipe rehabilitation projects for 48-inch diameter or greater pipes that were designed as a stand-alone system for a minimum total internal pressure of 150 psi within the past three years, and 3) drawings and calculations signed and sealed by a Professional Engineer licensed to practice in the State of Florida.

The CFRP manufacturer (HJ3) provided documentation and client references required to demonstrate the following: 1) written documentation showing the successful design of the CFRP system for the rehabilitation of at least five independent pipe rehabilitation projects for 48-inch diameter or greater pipes that were designed as a stand-alone system for a minimum total internal pressure of 150 psi within the past three years and 2) written documentation of a minimum of three pipe rehabilitations projects which have used CFRP termination details.

In addition to the requirements above, the materials required approval for use based on several criteria; the CFRP manufacturer was required to demonstrate the performance of the CFRP materials in full-scale tests as well as long-term durability. The CFRP manufacturer provided a full report of full-scale tests that met or exceeded the requirements as well as included a 20,000-hour aggressive durability test that demonstrated the CFRP material's ability to retain its strength after being exposed to various chemicals ranging from pH 2 to 12.5. The CFRP manufacturer also provided reports for the various independent lab tests performed on the CFRP materials to demonstrate tensile, compressive, and flexural properties.

Additionally, the CFRP manufacturer was required to maintain its NSF-61 Drinking Water Certification for all of the products which are used in the CFRP repair system. Part of maintaining the NSF-61 drinking water certification status involves compliance with surprise inspections to the CFRP manufacturer's facility for sampling random specimens of the CFRP system and submitting to an independent lab to assure that the system continues to meet the NSF-61 criteria. A full chain of custody is required for each and every shipment of CFRP materials, which starts with the allocation of raw materials, polymer blending, packaging, storage, shipment and delivery. The chain of custody is audited twice a year during unannounced visits by Underwriter's Laboratory (UL), a company that provides NSF-61 Drinking Water certification.

The CFRP manufacturer is required to furnish all Material Safety Data Sheets (MSDS), Technical Data Sheets (TDS), and certificates showing that the CFRP system complies with local regulations controlling use of Volatile Organic Compounds (VOC's).

REPAIR OVERVIEW

The first emergency repair project involved the internal rehabilitation of three (3) 20-ft sections of lock joint 54-inch diameter PCCP using CFRP. A recent condition assessment identified numerous pipe sections that were prioritized for repair. Three sections were deemed the highest priority for repair based on this assessment taking into account numerous factors including but not limited to: cracks, wire breaks, concrete de-laminations, ovality, and surface conditions. Two of the three pipe sections were located in a residential neighborhood and the third section was located five miles away in a busy intersection, both locations in North Miami Beach, Florida. The repair pipelines were located between access manholes that were approximately 2,200 lineal feet apart.

The second project involved the internal rehabilitation of four 20-ft sections of 48-inch diameter PCCP. These repair segments were located within the same line of pipe, although two of the segments were discontinuous and two segments were adjacent. The repair pipes were located between access manholes that were approximately 1,600 lineal feet apart. The access manholes were located in the center island that divided a four-lane highway in North Miami Beach, Florida.

The specifications, drawings, and aerial view maps were issued in tenders that required an emergency response by the winning contractor. Mobilization for the projects was executed three days after the contract award. All design documents, including engineering calculations, CFRP construction drawings and a ventilation plan, were generated and Florida sealed within the three-day window between contract award and mobilization. The CFRP materials, the quality control and the technical personnel were mobilized by the manufacturer. The CFRP manufacturer also provided a customized saturating resin impregnation machine for the efficient and thorough wet-out of the carbon fabric. The CFRP installer mobilized all ventilation, surface preparation equipment, job site tent, confined space equipment, safety personnel, CFRP technicians, and a large refrigerated reefer truck for cool storage of the CFRP materials.

Before work could begin, the pipe valve was turned off by the MDWSAD. The pipe was dewatered however, due to elevation changes along the run of pipe. As a result, there were several areas that had a large quantity of standing water left over that did not drain. This water required pumping and evacuation prior to beginning proper surface preparation. The line of pipe that was shut down was several thousand feet long, containing areas with large standing water at the bottom of slopes. The repair area between manholes required protection using in-situ dams and hydraulic sump pumps to ensure that no water would migrate into the repair areas in between the access manholes that contained the repair pipe sections.

A thorough inspection of the repair pipe was conducted to identify possible concrete de-laminations and hollow spots by means of an acoustic sounding test. The objectives of the repair pipe inspections were to locate any cracks in the pipe, determine the condition of the grout in the joint, ovality, and overall surface condition of the internal concrete lining of the pipe. ACI-546 "Concrete Repair Guide" standards were referenced when determining the width of cracks that should be injected.

In addition to a condition assessment of the repair pipe, the CFRP manufacturer and installer performed a visual inspection to all of the joints of the non-repair pipe. Upon inspection it was noted that many of the joints had lost 50-75% of their circumferential grout cover inside the joint. The joints were carefully documented by repair pipe section number and presented to the owner for repair. The repair pipe joints were prepared to the CFRP manufacturer requirements, which required exposing the steel cylinder to allow enough room for the galvanic insulator, bi-axial CFRP layer, and multiple uni-axial CFRP layers. The exposure also allowed for the expanded internal stainless steel termination ring to be installed with an epoxy grout cover.

Surface preparation was executed utilizing high pressure sandblasting with equipment large enough to sustain the greater than 2,000 lineal feet of sandblasting hose that was required to access at least one of the repair pipe segments. The goal of the surface preparation was to achieve a clean, dry surface with a minimum ICRI 03732 CSP#3 Concrete Surface Profile. The moisture content of the pipes was verified at $< 5\%$ as required prior to the application of the primer. The surface was verified to be clean by performing a dust test in multiple random locations after fully vacuuming the surface of the pipe. The steel cylinder was prepared to SSPC SP-10/NACE #2 "Abrasive Blast to Near White Metal". This standard when performed correctly is superior to hand tools, or wire wheel methods due to the effectiveness of the high pressure blast media to clean and profile the steel cylinder. The surface profile was measured using a film and gauge method, verifying at least 3-mils was achieved as required by the CFRP manufacturer.

Environmental parameters were monitored to ensure that the proper conditions were met throughout the duration of the project. Environmental monitoring instruments were utilized both at the epoxy mixing and impregnation stations as well as inside the pipe. The goal of the environmental condition monitoring was to record and ensure that the surface temp inside the pipe was at least 5 degrees Fahrenheit above the measured dew point. The humidity and ambient air conditions were monitored and recorded. De-humidification (DH) equipment was used as needed to control dew point and humidity in the air that was ventilated into the pipe. The DH equipment was used in addition to the constant ventilation equipment and air quality monitoring that was employed throughout the job for safe confined space entry.

The CFRP system was installed in the repair pipe sections according to the sealed drawings. Trained technicians monitored the quality of the epoxy mixing stations and fabric impregnation stations prior to sending the fully saturated, high-strength CFRP down into the pipe. All batches and lot numbers were recorded for each batch that was used, as well as meeting the minimum mixing time required for the epoxy components. The CFRP was freshly bagged and protected during transport from the access manhole to repair pipe. The trained technicians inside of the pipe installed the material per the requirements in the documents. The goal of any CFRP installation is to ensure that all fiber is applied smoothly and intimately with the application surface so that no bubbles, voids, wrinkles, or fiber misalignments are present. The trained technician is educated and experienced to follow the construction documents and achieve the proper development lengths required to make splices in the fabric in the circumferential and longitudinal directions.

A post-application inspection was performed at the start of each shift to ensure that any QC issues were remediated prior to commencing any new work. An acoustic tap test was utilized in addition to visual inspections to detect any anomalies in the installation. Termination rings were installed on top of the final layer of CFRP and expanded on top of the rubber ring to meet the force requirements of the manufacturer. The quality inspection of the termination ring was performed prior to the installation of the epoxy grout cover that was required to bring the elevation of the repair joint back to the original grade. A final application of top-coat was installed over the CFRP system, providing impermeable protection.

DESIGNING A PERMANENT REPAIR

The scope of the design for the CFRP system was to resist loads from earth pressures (soil, and groundwater), live loads, and internal pressure. The design was based on the maximum of the forces resulting from different load combinations while contemplating a 50-year design life assumption. The design working pressure was set to 150 psi, the Surge Rated Pressure was set to 200 psi, the Design Transient Pressure was set to 75 psi, the Vacuum Pressure was set to -14.7 psi, and the Live Load was set to AASHTO HS20 with two trucks passing. The soil measurements above the pipe were identified on drawings provided by MDWASAD. The CFRP system was designed as a stand-alone system for resisting pressure and bending. There was no structural support contemplated in the design from the original host pipe. The specification required a minimum 2.0 safety factor for design working pressure and transient pressure. The CFRP system was designed to have no more than a 2% vertical deflection when subjected to the external vertical load. Hydraulic performance was also calculated and insured to be in excess of that which existed prior to construction. Table 1.1 summarizes the design standard from the specification[3].

Table 1.1 Design Standard

Diameter	54-inch
Design Working Pressure	150 psi
Surge Rated Pressure	200 psi

Design Transient Pressure	75 psi
Vacuum Pressure	-14.7 psi
Soil Depth (above invert)	As shown on as-built plans
Type of Live Load	Equivalent to HS-20 (Check two trucks passing)

QUALITY CONTROL & TRAINING

HJ3 provided training to the MDWASAD inspector staff that would be involved in the day–to-day inspection, testing, and verification of all materials installed. The curriculum of the training was designed to provide the trainee with an understanding of CFRP materials and how they are manufactured, the full scale tests performed using CFRP retrofitted structures, Quality Control inspections throughout the CFRP installation, use of environmental condition instruments and recording, understanding the CFRP installation details, and knowledge about the requirements for CFRP termination details. The training was conducted for more than 25 personnel including all onsite members of the installer's Installation Team. An exam was issued and required at least a 70% or better in order to receive a certificate of training from the CFRP manufacturer.

CONCLUSION

Over the next two decades, an anticipated $1 Trillion will be needed to replace our nation's failing water transmission pipelines. Fortunately, a cost-effective alternative to pipe replacement dating back to the late 1960's is providing relief to municipalities and water authorities across the country. As our water transmission pipelines have corroded and degraded over the years, CFRP repair systems have become stronger and even more efficient at strengthening and extending the life expectancy. After decades of testing and approvals, including NSF-61 approval standards for potable drinking water applications, FRP repairs are extremely viable solutions and able to save owners 60-90% compared to replacement. In Florida alone, this could mean the estimated $12.8 billion that is required to replace the degraded transmission pipelines could be cut by as much as two-thirds. Emergency repairs are also more costly than regular maintenance. The utilization of a pre-qualified Team selected in advance for emergency repairs will help to cut these repair costs even further. After passing a rigorous pre-qualification process the manufacturer (HJ3 Composite Technologies) and installer (Lanzo Trenchless Technologies) were one of only two (2) teams selected to bid on the tender The execution of this tender was based on a high quality, proven Carbon Fiber Reinforced Polymer (CFRP) system designed to meet the expectations set forth in the specification including NSF-61 Certification, Fully Deteriorated Stand Alone Structural Characteristics, Improved Hydraulic Capacity, and a Ten (10) Year Warranty covering all materials and workmanship. These projects prove the effectiveness of HJ3's CFRP material design and quality control for PCCP rehabilitation.

REFERENCES

1) "Cathodic Protection Criteria for Pre-stressed Concrete Pipe - An Update" CORROSION 98, March 22 - 27, 1998

2) "Government Spending on Water Infrastructure" http://www.c-spanvideo.org/program/314107-5, July 22, 2013

3) "2013 Report Card for America's Infrastructure" http://www.infrastructurereportcard.org/a/#p/state-facts/florida.

4) "Emergency Interior Carbon Fiber Rehabilitation of Three (3) Lengths of 54-inch P.C.C.P. at NE 16th Ave South of NE 123 St, East Dixie Highway Near NE 85 St and at East Dixie Highway Near NE 10 Ave RPQ# PO087"