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REHABILITATION OF LARGE DIAMETER WATER MAINS WITH FRP LINERS AND LINER INSTALLATION PROCESS CONTROL

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АНОТАЦІЯ: Стаття висвітлює найважливіші аспекти оперативного та превентивного підходу до процесу безтраншейного ремонту напірних водогінних магістралей та забезпечення контролю якості установки систем реабілітації підземних трубопроводів в США.

АННОТАЦИЯ: Статья освещает важнейшие аспекты оперативного и превентивного подхода к процессу бестраншейного ремонта напорных водопроводных магистралей и обеспечения контроля качества установки систем реабилитации подземных трубопроводов в США.

ABSTRACT: This paper will serve to highlight the development of real time Quality Assurance approach for CFRP liners and how this process has aided in their overall document control and communication regarding PCCP asset management in the USA. Readers and attendees will gain valuable insight from one of the country’s most diligent and proactive PCCP owners.

KEY WORDS: Pre-stressed Concrete Cylinder Pipe, pipe materials rehabilitation.

INTRODUCTION

Pre-stressed Concrete Cylinder Pipe (PCCP) is the one of the most commonly used pipe materials for large diameter water transmission mains nationwide. This is common for most large municipalities of United States.

Because of aging of all infrastructures, including large diameter water transmission mains, industry utilizes all types of repair and rehabilitation techniques for rehabilitation of pre-stressed concrete cylinder pipe (PCCP),

counting extensive use of Carbon Fiber Reinforced Polymer (CFRP) liners for in-place trenchless repairs.

To ensure reliability of the pipeline rehabilitation a Quality Assurance and Control (QA/QC) Program was developed in collaboration with the manufacturer of the CFRP liner. The Program addresses all aspects of the CFRP lining installation process and has tailored QA/QC forms and procedures for the critical steps in the overall process. The accelerated construction schedule of typical CFRP lining projects made the implementation of a QA/QC program, which is managed online, ideal for ensuring close communication between all involved parties. In addition to facilitating communication during construction, the online project tracking system serves as the permanent archive for all documents related to the renewal of the pipeline system. The uploaded documents include original as-builts, plans, profiles, and specifications which address the original construction of the PCCP system. In addition, inspection results for the pipeline, preliminary CFRP lining drawings and calculations, construction photos and QA/QC records, and as-built CFRP lining drawings and calculations are stored in the system.

1 BACKGROUND

1.1 Aging of Pipeline Inventory and asset management program

Pre-stressed Concrete Cylinder Pipe (PCCP) is the one of the most commonly used pipe materials for large diameter water transmission mains in United States. While all pipelines in nationwide inventory are aging, the manner in which PCCP degrades segmentally, rather than uniformly along the length of the pipeline. Therefore, most of municipalities have placed increased focus on the integrity of their large diameter PCCP, since the consequence of failure for large diameter pipelines can be more severe in terms of impact on the water supply for a large number of customers, potential safety concerns, and widespread property damage.

Rather than opting for costly wholesale replacement of their entire inventory of large diameter PCCP, industry implemented a PCCP asset management program that identifies and provides targeted repairs for the segments of PCCP that exhibit signs of stress. This allows utilities to safely and efficiently manage their major PCCP transmission mains. It has been common experience that inspections typically identify approximately 2 percent of the total number of pipe sections evaluated in a pipeline as requiring repair. This low percentage of deteriorated pipe sections lends itself to the targeted repair strategy that industry has adopted, versus total replacement.

In order to assess the condition of a PCCP main, different inspection

technologies that do not require excavation of the pipeline are used. These inspection technologies include visual and sounding of the inner concrete core, electromagnetic inspection, sonic/ultrasonic testing, and concrete strength testing. Pipe excavation for validation and confirmation of condition assessment results are also performed, as needed. Once a pipeline is inspected and the condition of the line is assessed, acoustic fiber optic (AFO) cables being installed to continuously monitor the pipeline for future degradation activity.

Deteriorated pipe segments are typically either replaced or internally strengthened using Carbon Fiber Reinforced Polymer (CFRP) composites. In urban areas or locations where dig and replace is challenging, or disrupts the surrounding environment and heavy traffic, the use of internally applied CFRP provides a distinct advantage as a trenchless solution in which no excavation of the pipeline is required.

1.2 Summary of Internal Strengthening of Pipelines with CFRP

The use of CFRP for internal rehabilitation and strengthening of PCCP has been performed with increasing frequency nationwide since the mid-1990s. The installation of an internally applied CFRP system includes surface preparation and dehumidification of the concrete substrate, mixing of the epoxy material, saturation of the reinforcement fabric with the mixed epoxy, application of the saturated sheets on the internal surface of the pipe as shown in Fig. 1, and detailing of the liner termination at the pipe joints. Using CFRP composites for PCCP repair requires a thorough construction specification, specially trained construction inspectors, as well as a detailed inspection protocol for quality assurance.

Fig. 1. Installation of an Internally Applied CFRP System

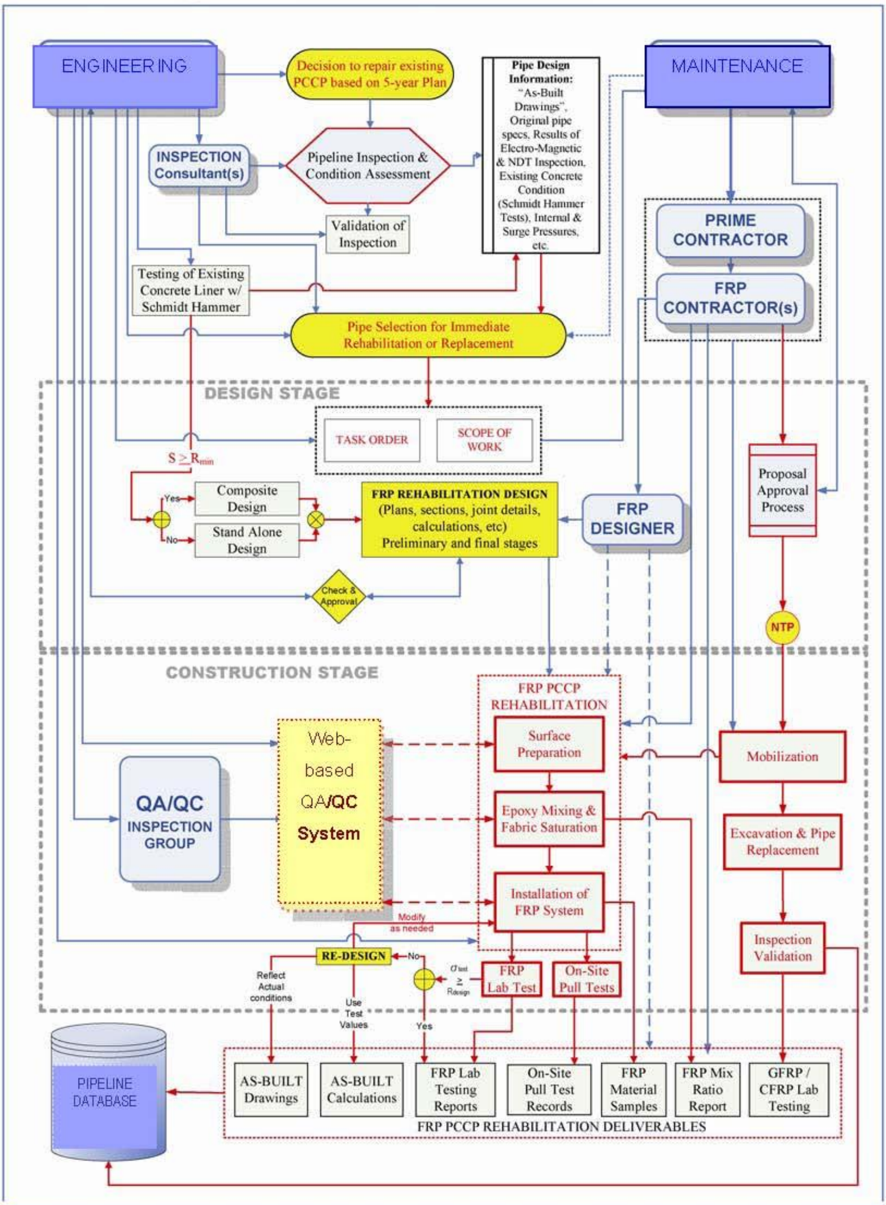

Fig. 2. Work Flow Chart for pipeline rehabilitation Program

Once installed, the CFRP system serves as a structural element to provide

integrity to the pipeline. It resists all loads that act on the pipeline including internal pressure, vacuum, soil loads, and vehicular traffic as well as the combined effects of the different loading conditions. The number of layers of carbon fiber reinforcing fabric applied in the longitudinal and circumferential direction is determined by the detailed design requirements which are provided in specifications and project specific scoping documents. Because of the highly technical nature of the internally applied CFRP system, the materials, design, and installation of the CFRP system is provided as a turn-key package by an experienced CFRP contractor. This ensures quality control over the overall process.

2. WORK FLOW FOR PCCP MANAGEMENT PROGRAM

Shutdown times for large diameter water mains shall be minimized as much as possible due to the lack of redundancy in water supplying systems. Minimizing shutdowns reduces the strain that having these large diameter pipelines out of service places on the rest of the water supplying system. Significant planning is required to schedule shutdowns during periods of low water demand and coordinating inspection, rehabilitation of the pipelines, as well as quality control during these periods. An example of work flow which illustrates the detailed coordination efforts required to implement a successful pipeline rehabilitation program is shown in Fig. ***2***.

The documentation and tracking of work flow, associated with pipeline rehabilitation program, is managed using a web-based system which is managed by municipality engineers and contractors. The value of this online program is particularly highlighted during implementation of CFRP rehabilitation projects in which the use of the program for storage of all project files provides for continuous QA/QC, allowing for clear and transparent information for the entire team.

2.1 Inspection and Condition Assessment Phase

Engineering and Maintenance Divisions worked together on the development of PCCP inspection and rehabilitation plan which establishes the priority and sequence of inspections.

Once a given pipeline is identified for inspection, detailed planning occurs. This includes review of pipeline as-built drawings, pipe lay schedules, and pipe design specifications. The PCCP condition assessment includes leak testing, followed by shutdown of the main and complete dewatering. The pipe is

then inspected using a certain inspection protocol, which consists of mapping and pipe numbering, visual inspection and sounding, electromagnetic testing, and sonic/ultrasonic testing.

After the pipeline inspection and condition assessment is performed, all inspection data is consolidated and results are analyzed. Based on the inspection data, repair or replacement prioritizations are made that include analyzing the risk of failure for a pipeline segment. Inspection results are validated as needed through excavation of select pipeline segments for verification. Based on the location and ease of excavation of the distressed pipe segments, engineers determine the appropriate technology for addressing the deteriorated pipe segment.

2.2 CFRP Rehabilitation Design Phase

After the pipe sections requiring CFRP rehabilitation are selected, Engineers prepare the scope of work for the project. The scope includes pipe design and record data, and inspection results, along with detailed design requirements. Concurrently, Engineers enter the dewatered pipe to conduct concrete testing of the inner core of pipe to be repaired in order to gather information needed for the design of the CFRP system. Once the scope of work for the project is developed, the Designer can proceed with the design. The design and all submittals for the CFRP system are developed by the contractors, and then uploaded to the web-based system. While municipal engineers review design submittals the project inspectors participate in the QA/QC planning so they are familiar with the construction documents in advance of construction.

2.3 CFRP Rehabilitation Construction Phase

Upon approval of the CFRP design and technical package, the contractors mobilize to the site to perform the work. The general contractor handles dewatering of the pipeline, traffic control, and other project site logistics. The CFRP subcontractor handles all aspects related to the CFRP installation. These include controlling the pipeline environment to provide proper ventilation and dehumidification, preparation of the inner core concrete substrate, adhesion testing to verify surface preparation mixing of the epoxy, saturation and installation of the reinforcing fabric, top coating, remediation of any defects, fabrication of test panels, and documentation of QA/QC. A summary of the QA/QC documentation process is described in following Section.

3 OVERALL QA DOCUMENTATION PROCESS

QA/QC process is managed by the municipal engineers, the CFRP rehabilitation subcontractor and their design engineer, as well as municipal project inspector. This effort is tracked using the same web-based system utilized for coordination of activities for the inspection and condition assessment. The use of this web-based system for QA/QC has proven to be the ideal tool for submitting and reviewing contractor designs and storing large amounts of project design information. It allows the contractor to send electronic submittals for the municipal engineers to easily retrieve and review CFRP designs, conduct QA/QC and confirm compliance of each procedure in a timely manner that facilitates the expedited construction process.

3.1 QA/QC Documentation of the CFRP Rehabilitation Process

In order to aid permanent record keeping for the project, a record in the system for each rehabilitated pipe section is initiated. This includes the identifying pipe number, location, and specifics of the rehabilitation. This record also includes all design, inspection, repair, and as-built information related to the individual segment of pipe. For documentation of the CFRP repair, separate QA/QC forms are created for each segment of PCCP to be repaired. Each individual QA/QC form documents the complete lining installation process, including the date of completion, inspection/verification of the installation process, lot numbers of materials used, notes regarding unique field conditions, and the personnel involved in the QA/QC documentation process.

After the QA/QC form information is completed by the CFRP rehabilitation subcontractor, QA/QC inspector verifies the information, approves, or sends back for revisions. The developed process allows for detailed construction records to be created with input from multiple participants. It also streamlines the process of document control. The major aspects of the QA/QC documentation throughout the installation process are noted below. Each procedure is controlled and documented for quality assurance and compliance with specifications.

3.1.1 Concrete Integrity Testing and Surface Preparation

A properly installed CFRP system adheres strongly to the pipe wall. Therefore, the CFRP system can either be designed as a composite system, using the existing pipe and the CFRP to resist design loads, or the CFRP system can be designed as a stand-alone system where no strength contribution from the existing structure is considered. A process for determination of whether a

pipeline should be designed as stand-alone versus composite involves integrity esting of the inner core concrete using a digital Schmidt hammer, as shown in Fig. 3 or other non-destructive testing (NDT) techniques allowing to obtain compressive strength values for the inner core concrete. The median compressive concrete strengths will be used for design. If the concrete strengths are below a certain threshold, as determined by the design engineers, or if visual or other inspection results indicate severe degradation, engineers make the determination which system should be used for design.

Fig. 3. Use of a Schmidt Hammer for Testing the Concrete Structural Integrity

Prior to installation of the CFRP material, the interior concrete substrate is prepared with an ultra-high pressure water blaster. The water blast exposes the aggregate as shown in Fig. 4a and ensures appropriate adhesion between the CFRP system and the existing pipe. The concrete-to-CFRP adhesion strength is verified using an adhesion test in compliance with ASTM D4141, as shown in the Fig. 4b. After the surface is properly prepared and the pipe walls have dried, additional repairs to the interior pipe surface can be conducted if necessary to restore a consistent profile.

As part of the QA documentation process, the QC inspector verifies that all surface contaminants (laitance, surface lubricants, scaling, etc.) have been removed. The inspector also verifies that the prepared surfaces have been checked for moisture and have been observed to be clean and dry.

a) *b)*

Fig. 4. QA/QC Procedures Associated with Surface Preparation:
a) Concrete Substrate with Exposed Aggregate;
b) ASTM D4541 Adhesion Testing

3.1.2 Epoxy Mixing and Fabric Saturation

During the mixing of the epoxy, the QC inspector verifies that only materials approved for use on the project have been utilized, and that the expiration dates of the epoxy systems utilized are within their shelf life.

Fig. 5. Calibrated Mechanical Saturator Utilized for Ensuring Complete Fabric Saturation

The QC inspector also verifies the epoxy components were mixed from pre-proportioned and pre-packaged containers and there is a uniform and complete mixing of components.

During the saturation of the reinforcing fabric, the QC inspector verifies the calibration of the mechanical saturator equipment at the beginning of each shift and ensures the CFRP contractor adjusts the initial roller gap, as needed, for the saturator to achieve the manufacturer specified fabric saturation. Additional verification of the fabric saturation calibration is performed at the discretion of the inspector. The saturation of the carbon fiber fabric is shown in Fig. 5.

3.1.3 CFRP System Installation

During the QA/QC inspections, the QC inspector is tasked with the following tasks:

Primer/Rendering- Verify that all surface irregularities have been filled with thickened epoxy and the primer has been uniformly applied to all areas.

Fabric Placement- Verify that the reinforcing fibers have been placed with sufficient epoxy to achieve full saturation of the fibers and the appropriate number of layers and direction of layers have been applied and is within project tolerances. Overlaps- Verify that fabric overlaps are in compliance with the specifications.

End Details-Verify end details are installed in compliance with the project drawings and specifications (Fig. 6).

Fig. 6. Inspection of the End Connection Detailing at the Joints

Top Coat- Verify a top coat of thickened epoxy, has been applied after the installation of the end details and any entrapped air between layers has been released prior to the resin sets.

As the CFRP installation progresses, there is continuous QA/QC inspection of the process at each installation step. Test sample panels are produced by the carbon fiber contractor. After they are fabricated, the samples are sent to an independent laboratory for tensile tests performed in accordance with ASTM D3039.

The QC inspector performs a thorough examination of the installed CFRP system checking for defects and confirming compliance with the CFRP design. If there are any deficiencies, the size and character of the defects are noted along with longitudinal and circumferential location. The contractor makes any repairs, notating the date and method of repair, followed by re-submittal of the installation QA/QC report.

A final walk-through inspection is necessary to receive final approval. During this inspection, any defect remediation is checked and confirmed. Upon municipal engineer approval, a final one page QA/QC report is generated for each pipe section at completion.

Fig. 7. Inspection of the Completed CFRP Liner

4 BUILDING A LEGACY

The Web-based QA/QC System is a vital tool to ensure reliability of the CFRP rehabilitation work. The CFRP pipeline rehabilitations being installed will be in place long after the author of this paper have retired. Due to innovative QA Program, there will also be a permanent record of each step of the asset management process for critical pipelines.

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