depending of the location of the pipeline. The sand came from gravel pits along the South Platte River. The quality of the material varied depending on how far the pit was from the mouth of the South Platte River Canyon near Waterton, CO. The material mined near the mouth contained a lot of fines and was difficult to consolidate. Material mined further downstream was cleaner and produced the desired results. This resulted in the limit of 3% fines (minus No. 200) material in the subsequent allowable gradation.

In 1976 Denver Water started listing the sand gradation in project specifications. This was done to obtain consistency in the sand supplied so that the consolidation could be accomplished with a minimum of arguments with the contractors. The sand gradation was listed as follows:

Sieve Size	Total Passing by Size (Percent by Weight)
3/ 8 inch	100
No. 4	70-100
No. 8	36-93
No. 16	20-82
No. 30	8-65
No. 50	2-30
No. 100	1-10
No. 200	0-3

Currently the Denver Water Engineering Standards list the requirements for pipe zone material as being clean, free draining, well graded sand with the following gradation:

Sieve Size	Total Percent Passing by Weight
3/8 inch	100
No. 4	70-100
No. 8	36-93
No. 16	20-80
No. 30	8-65
No. 50	2-30
No. 100	1-10
No. 200	0-3

The Denver Water Board has installed about 2500 miles of pipe; 500 miles of pipe larger than 24 inches in diameter. About half of that has been installed since 1960 using the jetting and vibrating method. The largest pipe installed using this method is 144 inches.

CASE STUDIES

Bureau of Reclamation - Gradation

About 1980, Reclamation only allowed clean gravels compacted by saturation and vibration as pipeline bedding and embedment. Several field trials were used to establish the best gradation and the effectiveness of the procedure.

As clean gravels are dumped into a stockpile, the larger particles tend to roll to the perimeter of the stockpile. Dumping gravels containing 3 inch particles in beside a pipeline created rock pockets in the haunches of the pipe. Experimentation to find the optimum gradation to prevent these rock pockets resulted in the following gradation:

The gradation for optimum flow characteristics is:

Passing No. 200 sieve 5% or less.
Passing No. 50 sieve 25% or less.
Passing ¾-inch sieve 100%.

Basically, the material must have few fines, not much fine sand, and have a maximum particle size of 3/4 inch *(20 mm).*

Bureau of Reclamation – McGee Creek Aqueduct

The results of the first attempt by a contractor inexperienced with saturation and vibration is shown in Figure 6. There were too many fines in the soil used as evident by the crust on the surface. The contractor ordered the material appropriately with 5% fines or less. However the aggregate processing plant sent the wrong material. Once the correct soil was being used, he successfully completed the job.

Figure 6 Too Many Fines for Saturation and Vibration

SUMMARY

Proper buried pipeline installation relies on support for the pipe in the haunch area. This is necessary for all types of pipe material. One method of obtaining haunch support is by using cohesionless soils and providing compaction by using saturation and internal vibration (jetting and vibrating). The method uses internal concrete vibrators and enough water to lubricate the soil particles.

The method has two significant advantages: (1) the soil in the pipe haunch area can be effectively compacted to a high density, and (2) the compacted lift thickness can be several feet thick, limited by only the length of the vibrator.

The disadvantages of saturation and vibration are floating the pipe if too much water is used and sometimes a trial test section is necessary to arrive at the right combination of water, equipment, and procedure.

Denver Water has been utilizing this method since the 1960s. US Bureau of Reclamation has been using the method since the 1950s and at one time saturation and vibration was the only acceptable compaction method for pipe embedment.

REFERENCES

ASTM F 1668 *Practice for Installing Thermoplastic Pipe*

ASTM D 4253 *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Tabl*e.

ASTM D 4254 *Standard Test Methods for Minimum Index Density of Soils and Calculation of Relative Density*

Boschert, J. and Amster Howard (2014) *Importance of Haunching*, Proceedings ASCE Conference Pipelines 2014, Portland OR

Holtz, W.G. (1957) *Experience with the Consolidation of Pipe Bedding by Vibration on the San Diego Aqueduct*, ASTM STP 206 *Papers on Soils*

Howard, Amster (2009) *Uniform Soil Groups for Pipe Installation*, ASCE Proceedings of Conference Pipelines 2009, San Diego CA

Howard, Amster (2015) *Pipeline Installation 2.0*, Relativity Publishing, Lakewood CO

Lee, K.L. and A. Singh (1971) *Relative Density and Relative Compaction*, Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. 7

Sailer, R.E (1955) *Bedding and Backfill Methods Save Reinforcing in San Diego Aqueduct*, Civil Engineering May 1955, American Society of Civil Engineers

Sayreville Relief Force Main: 10 Years of Monitoring and Proactive Management

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Abstract

Proactive management, monitoring, and rehabilitation of pipelines are common phrases used in the water and wastewater industry today. Over the last 10 years, tools and techniques have rapidly evolved, providing utilities with a plethora of options for pipeline assessment and management. Because proactive management and monitoring are only recently being widely implemented across the industry, few long-term case studies documenting the success of these practices are available. This paper will discuss the monitoring and proactive management of the 102-inch Sayreville Relief Force Main, which has been actively monitored and routinely inspected for the last 10 years. When the Sayreville Relief Force Main experienced its second failure in March of 2003, many of the common techniques for condition assessment and asset management were just being introduced to the industry. Due to known deficiencies associated with Interpace PCCP manufactured in the 1970s, aggressive soils, and an environmentally sensitive surrounding area, the force main's owner and operator, Middlesex County Utilities Authority (MCUA), began a program of inspection, assessment, and active monitoring. Over the 10-year management period, monitoring evolved from a surface-mounted sensor (SMS) system to an acoustic fiber optic (AFO) monitoring system, and the assessment techniques grew from visual and sounding inspections and electromagnetics to include sonic/ultrasonic testing, and advanced structural analysis. Through this program, MCUA has proactively rehabilitated deteriorating pipes, preventing catastrophic failures. A study of the evolution of the program for the Sayreville Relief Force Main can serve as a resource for other water and wastewater utilities, who will benefit from the lessons learned and the advantages gained over 10 years of proactive management.

Introduction

MCUA provides wastewater treatment services for over 800,000 residents of central New Jersey. One of the largest pipelines in the MCUA system is the 102-inch Sayreville Relief Force Main, which extends 18,700 feet from the Sayreville Relief Pump Station to the Edward J. Patton Water Reclamation Facility. When the Sayreville Relief Force Main experienced its second failure in March of 2003, many of the common techniques for condition assessment and asset management were just being introduced to the industry.

The Sayreville Relief Force Main comprises 102-inch prestressed concrete cylinder pipe (PCCP) – embedded cylinder type (ECP). This particular design includes an inner concrete core, a thin steel cylinder, an outer concrete core, high-strength steel prestressing wire, and a mortar coating. The prestressing wire is wrapped helically around the concrete core to hold the concrete in compression when internal and external loads are applied. The concrete cores and prestressing wire provide the structural strength for the pipe while the steel cylinder provides water tightness and the mortar coating protects the prestressing wire wraps. The ECP in the Sayreville Relief Force Main was manufactured by Interpace Corporation (Interpace) in the late 1970s. The deficiencies of Interpace pipes manufactured in the 1970s are well documented and were most particularly related to the manufacture of the prestressing wire.

The 2003 failure in the Sayreville Relief Force Main was attributed to acidic soils that deteriorated the mortar coating of the pipe and lowered the pH of the coating. No longer protected by the alkaline environment, the wire was exposed to a corrosive environment. Additionally, the Interpace 8-gage, Class IV prestressing wire used in the Sayreville Relief Force Main is known to be particularly susceptible to hydrogen embrittlement and poor torsional ductility. This combination led to sudden, brittle breaks in the prestressing wire wraps. Broken prestressing wire wraps ultimately led to the failure of the pipe.

The first investigations of the Sayreville Relief Force Main focused on identifying any pipes in immediate danger of failure as well as pipes with low to moderate levels of damage. The investigative techniques included visual and sounding inspection to identify pipes in a state of incipient failure, electromagnetic inspection to identify pipes with broken prestressing wire wraps, and soil and groundwater testing. Following the internal inspections, a continuous acoustic monitoring system was installed to track prestressing wire wrap breaks in near real time.

Since MCUA implemented the assessment program in 2003, the Sayreville Relief Force Main has been inspected in its entirety three (3) times, 2003, 2008, and 2013, with a number of shorter, targeted inspections performed in the intermediate years. Since that time, the original inspection techniques have been improved and new tools were also introduced.

Evolution of Inspection Tools and Techniques

Since the failure in 2003, numerous tools and techniques have been used to evaluate the Sayreville Relief Force Main. The following sections detail how these inspections have been conducted in the Sayreville Relief Force Main and how they have evolved since the first comprehensive internal inspection in 2003.

Visual and Sounding Inspection

The visual and sounding inspection methodology has remained largely unchanged over the 10 years that the condition assessment program for the Sayreville Relief Force Main has been in place. In fact, Openaka Corporation, Inc. (Openaka), now owned by Pure Technologies U.S. Inc., refined the current visual and sounding techniques for PCCP in the early 1990s.

Visual and sounding inspections are used to detect pipes in a state of incipient failure. During the visual and sounding inspections, the interior of the Sayreville Relief Force Main was inspected for cracks, spalls, and other signs of distress. Additionally, a steel rod was used to strike the interior surface of the pipes to detected hollow areas. It has been shown that longitudinal cracks at the springline with carbonate staining, hollow areas, and especially a combination of the two, can be indicators that a pipe is in a state of advanced distress (Lewis and Wheatley). Figure 1 shows an inspector sounding during the 2013 internal inspection.

Figure 1. Inspector Sounding the 102-inch Force Main

Electromagnetic Inspection

While a visual and sounding inspection identifies pipes in a state of incipient failure, it cannot detect pipes with minor to moderate levels of distress. To complement the visual inspection, electromagnetic inspections of the Sayreville Relief Force Main are also performed. An electromagnetic inspection is a nondestructive method used to evaluate the current condition of the prestressing wire wraps. Pipes in a state of incipient failure typically have a large number of broken wire wraps.

Electromagnetic inspections of the Sayreville Relief Force Main began in 2003. The theory behind this technology was that a varying electromagnetic field is applied to the helically-wrapped prestressing wire. Discontinuities in the prestressing wire (i.e., broken wire wraps), alter the field (Lewis and Wheatley). Changes in the detected field are measured and can be used to locate and quantify distressed regions in PCCP.

The theory behind electromagnetic inspection has not changed in the 10 years that the condition assessment program for Sayreville Relief Force Main has been in place. What has been improved is the configuration of the inspection tool. The detectors in the original tool were oriented in such a way that any non-uniform pipe properties were detected. The newest tools have adjusted the configuration of the detectors so that they specifically look for changes in the prestressing wire. Additionally, as more pipelines were inspected and results were validated, analysis of the inspection results was refined and improved.

Continuous Acoustic Monitoring

Large areas of broken prestressing wire wraps can lead to catastrophic failure of a PCCP. Unfortunately, PCCP does not fail in a uniform manner and large amounts of damage can occur in a relatively short period of time. To monitor the Sayreville Relief Force Main in between manned internal inspections, MCUA opted to install continuous acoustic monitoring equipment to detect wire wrap breaks as they occurred in near real time.

Because the Sayreville Relief Force Main conveys wastewater, a surface mounted sensor (SMS) system was chosen to continuously monitor the pipeline for wire wrap breaks. The first monitoring system, which was installed in January 2004 following the first internal inspections, consisted of surface mounted sensors attached to accessible appurtenances on the exterior of the force main. These sensors detected the wire wrap breaks and transmitted the results to a central computer. MCUA personnel received notifications of wire wrap breaks via e-mail (Fitamant, Lewis, et al.).

Following the 2008 and 2013 inspections, new acoustic fiber optic (AFO) systems were commissioned in the Sayreville Relief Force Main. Unlike the SMS system, fiber optic cable was installed along the entire length inside the force main. Wire wrap breaks can be recorded at any point along the cable and the information about a particular break is transmitted back to a processing computer along the pipeline. Figure 2a and Figure 2b show internal and external views of a splice point at a manhole in the current MCUA AFO system. At splice points, runs of fiber optic cable from different portions of the pipeline are connected to create one continuous system.

Figure 2a. Internal AFO Splice Point at MCUA

Figure 2b. External AFO Splice Point at MCUA

Although notifications are still sent to MCUA via e-mail, all wire wrap break data is also accessible on a website that allows MCUA personnel to view the wire wrap break history for the entire force main.

Structural Modeling

As noted previously, when a visual and sounding inspection detects a pipe with a hollow area and longitudinal cracking, it typically indicates a pipe in a state of incipient failure. It is then a fairly straightforward decision to repair pipes with this level of distress. When the results from an electromagnetic inspection and acoustic monitoring are considered, the question becomes at which level of prestressing wire damage does action need to be taken to mitigate the risk of catastrophic failure.

Structural modeling can be used to evaluate the condition of a PCCP design with varying numbers of broken prestressing wire wraps. To evaluate the results for pipes with minor to moderate levels of distress, MCUA opted to perform structural modeling to assist in management decisions for the Sayreville Relief Force Main. This allowed MCUA to schedule future rehabilitation work rather than needing to perform immediate repairs because a pipe had a very high risk of failure.

Following the 2003 inspections, two-dimensional finite element modeling was used to investigate the results of the electromagnetic inspection and the AFO monitoring. The PCCP was modeled as a two-dimensional beam on an elastic foundation. The cross section of the pipe was transformed into an equivalent concrete section and the radial stiffness of the pipe was used as the spring stiffness of the elastic foundation. The compression applied by the prestressing wire, the internal water pressure, and any external loading were combined via the principle of superposition and applied to the beam. The beam deflection calculated in the analysis could then be equated to the stress generated in the concrete. That level of stress was compared to the compressive strength of the concrete to determine when visible cracking would occur (Fitamant et al.).

Since the initial structural evaluations, advancements in computer processing capabilities led to the use of comprehensive three-dimensional, nonlinear finite element modeling of the 102-inch ECP designs used in the Sayreville Relief Force Main. In these evaluations, the PCCP design could be modeled as a pipe, with each of the cross section components acting as a layer in a composite element. The pipe that is ultimately modeled is a collection of thousands of individual elements. Figure 3 shows the hoop stresses developed in the prestressing wire layer of a 102-inch PCCP with 35 broken wire wraps.

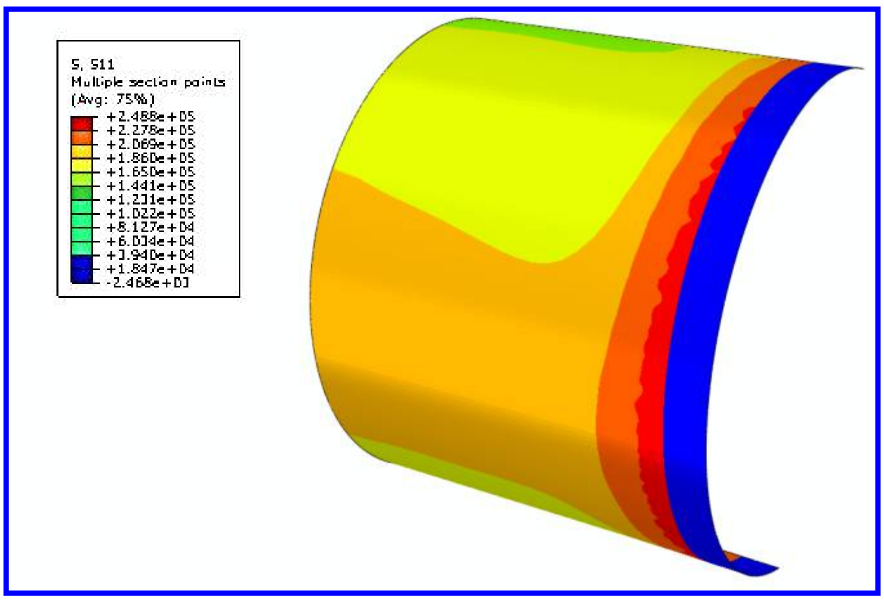

Figure 3. Hoop Stresses Developed in the Prestressing Wire Layer