ROCKY MOUNTAIN CHAPTER

2017

Rocky Mountain Trenchless Journal

Manhole Rehabilitation in Denver

ALSO INSIDE:

- Innovation in Guided Boring
- Eldorado Springs CIPP Work
- News from NASTT, & More!

FALL 2017

Rocky Mountain Trenchless Journal

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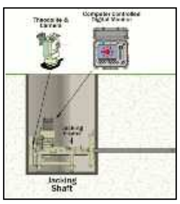

Also...

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Forward on our Mission

Joseph Lane
Chair, RMNASTT

Welcome to another issue of Rocky Mountain Trenchless Journal! I'm honored to serve as the RMNASTT Chair alongside a dedicated Board of Directors committed to advancing the trenchless industry. Our board and numerous dedicated committee members represent a broad section of our industry which includes contractors, manufacturers, design professionals, and public works and utility departments in service of our mission: to advance the science and practice of trenchless technology for the public benefit by promoting education, training, research, development, and information; and to disseminate, through public forums, the improvements and status of trenchless technology.

RMNASTT was formed in 2009 to promote education and implementation of trenchless technology for the public interest throughout the states of Colorado, Utah, Montana and Wyoming. This year we are excited to announce the expansion of our chapter to include Kansas, Nebraska, South Dakota and North Dakota. We ask for your help in identifying champions of the trenchless industry in these states who will help us grow our membership and educational opportunities.

RMNASTT was very proud to host the highly successful 2015 No-Dig Show in Denver, setting an attendance record which has yet to be surpassed. Given the excellent feedback from NASTT membership and the high level of trenchless interest from the Rocky Mountain region, we are excited to have once again been chosen to host the No-Dig Show, this time in Denver in 2020. Local involvement is critical to the success of the No-Dig Show, so we will be counting on you to help us break even more records this next time around!

"We are excited to announce the expansion of our chapter to include Kansas, Nebraska, South Dakota and North Dakota"

One of the goals identified by our Board of Directors is to engage a larger group of trenchless professionals to participate in the many educational opportunities provided by NASTT. RMNASTT and NASTT have a wide variety of volunteer openings that allow for satisfying and rewarding involvement at any level. If you are interested in more information, please visit our website at nastt.org/volunteer. There you can view our committees and learn more about NASTT's goals. Please consider becoming a volunteer – we would love to have you.

Following successful sporting clay events in Utah and Colorado this year, please watch for our upcoming outreach and young professionals events. NASTT has a very promising future, and your Rocky Mountain Chapter is stronger than ever.

After an excellent 2016 RMNASTT annual regional conference in Utah last year, we have high expectations regarding our conference's return to Colorado this November 7 and 8 at the Westminster DoubleTree. We are happy to once again welcome the return of a full day of regional paper presentations, exhibitors, and networking opportunities on the 7th and the highly acclaimed CIPP short course on the 8th.

The regional conference takes a lot of effort, and I would like to thank conference chair Benny Siljenberg and the entire RMNASTT Board of Directors and volunteers for a job well done.

2018 will be filled with opportunity for RMNASTT. To find out more about our activities and to get involved, please contact me or visit www.rmnastt.org. For more information about NASTT, including membership in the organization, please visit www.nastt.org.

Lastly, a sincere "Thank you" to our dedicated sponsors who provide our chapter with the resources necessary to forward our goals. On behalf of the board, we look forward to seeing you soon at one of our upcoming events!

Joseph Lane, *Chair*
NASTT Rocky Mountain Chapter

Members Make It Happen

Frank Firsching
NASTT Chair

Hello, Rocky Mountain Chapter members! We are well into the year, and I'm excited for the future during my term as Chair of NASTT's Board of Directors. NASTT's 2017 No-Dig Show and ISTT's 35th International No-Dig in Washington, D.C., were very successful on all accounts. The exhibit hall was a sell-out once again, and we experienced excellent attendance. We were thrilled to host delegates from all over the globe.

The North American Society for Trenchless Technology exists because of the dedication and support of our volunteers and our 11 regional chapters. There are several Rocky Mountain Chapter members that serve on our No-Dig Show Program Committee and volunteer their time and industry knowledge to peer-review the abstracts.

We're looking forward to the upcoming NASTT's No-Dig Show in Palm Springs, California, next March 24-29. These 2018 committee members from the Rocky Mountain Chapter will ensure that the technical presentations are up to the standards we are known for: Annalee Collins, Robin Dornfest, Jeff Maier, Jon Nix, Swirvine Nyirenda and Benny Siljenberg.

The Rocky Mountain Chapter is also home to some of No-Dig's Session Leaders. Session Leaders are Program Committee members who have the added responsibility of managing a session of the technical program and working with the authors and presenters to facilitate excellent presentations. I would like to extend a special thank-you to the Rocky Mountain Chapter members who will also serve as Session Leaders in 2018: Annalee Collins and Robin Dornfest.

In addition to the annual No-Dig Show, NASTT provides many trenchless training courses. We are focused on trenchless education, and our highly experienced instructors and presenters are dedicated to trenchless education, providing their expertise strictly on a volunteer basis. They donate personal time to travel around North America to provide high-quality training on a host of trenchless technologies.

I would like to thank Rocky Mountain Chapter member and NASTT Board of Directors member Jeff Maier for serving as a presenter this year. Jeff volunteered for our Trenchless Trends Forum at the UCT Show in Texas earlier this year and will be moderating our upcoming webinar on November 7: NASTT's Sealing a Collection System Webinar. Visit nastt.org/training/events to register for this free webinar. Jeff also teaches our Introduction to Trenchless Technology Rehabilitation Course. Thank you, Jeff.

The Rocky Mountain Chapter has a great local conference coming up in November – Trenchless Elevated 2017! Be sure to make your plans to attend this event for grassroots networking and top-notch trenchless education. You can read all about it in the following pages.

NASTT is a society for trenchless professionals. Our goal is to keep our finger on the pulse of our industry and provide beneficial initiatives. To do that, we need involvement and feedback from our professional peers. If you are interested in more information, please visit our website at nastt.org/volunteer. There you can view our committees and learn more about these great ways to stay involved with the trenchless community and have your voice heard. Please consider becoming a volunteer – we would love to have you get more involved.

NASTT has a very promising future because of our amazing volunteers. Thank you again for your continued support and dedication to NASTT and the trenchless technology industry.

Joseph Lane - *Chair*

Mr. Lane is president of Lane Consulting Group, LLC, and former president of HEBNA Corporation. He holds a bachelor's degree in biology from the University of Northern Colorado and is a graduate of the University Of Michigan School Of Business Management and the Leadership Program of the Rockies. Prior to Lane Consulting Group and HEBNA, Joe spent more than 23 years with SAK and Insituform Technologies. He is a regular speaker and instructor at numerous industry and educational associations such as the Water Environment Federation, American Public Works Association and NASTT.

Chris Larson - *Co-Chair*

Mr. Larson is a vice president of C&L Water Solutions, Inc. out of Littleton, Colorado. He has been immersed in the trenchless field with particular focuses in sliplining, pipe bursting, UV CIPP, lateral rehabilitation, and manhole rehabilitation. He contributes to the advancement of quality-focused applications of trenchless technologies for unique and challenging project applications.

Stephanie Nix-Thomas - *Treasurer*

Stephanie Nix-Thomas is president of Claude H. Nix Construction Co. in Ogden, Utah. Since 2002, the company has been committed to expanding the choices of underground utility owners for quality installations and rehabilitation of their pipelines. Her particular focus is in jack and bore (GBM, ABM, TBM), pipebursting, pipe ramming, and sliplining. She is committed to advancing trenchless technologies and believes that NASTT is one of the best educational resources.

Benny Siljenberg - *Secretary*

Mr. Siljenberg, P.E., MBA, is a founder and vice president of Lithos Engineering. His experience in both design and construction management allows him to understand what projects require from beginning to end. Benny's career has focused on underground design and construction projects, primarily in Colorado, affording him an in-depth understanding of the different ground conditions around the state. Benny's enthusiastic approach to his work brings energy to his project teams and accompanies his vast underground technical expertise. This unique combination proves to be a valuable resource on underground engineering and construction projects.

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Welcome to Trenchless Elevated

Benny Siljenberg
Conference Chair

As every year passes and our nation's infrastructure ages, I am continually impressed by the adaptation and innovation of the people that make up the trenchless industry. Trenchless design and construction continue to adapt to meet the challenges of our rapidly growing society. The fruits of the trenchless industry's solutions-driven attitude have helped our society better manage the complicated task of installing new and rehabilitating existing infrastructure required to keep our communities operating at the levels they not only require but deserve.

In helping to advance trenchless technology, promote its benefits, and increase awareness and knowledge through research, development, education, and training, I have become a better civil engineer. My involvement in NASTT and the tunnel and trenchless industries has afforded me the opportunity to collaborate with some of the best people in our line of work. I am privileged and humbled to have had the opportunity to work with many of you and do my part in solving our ever-increasing infrastructure challenges.

I became aware of the benefits of trenchless technology early in my career, and its practicality became clear as I watched our industry grow. I have relied upon the wisdom and experience of those who share their trenchless experiences. It is through these educational and networking components of the industry that owners, contractors, engineers, and suppliers find value in NASTT. Our local Rocky Mountain Chapter (RMNASTT) was formed in 2009 to promote the education and implementation of trenchless technology for the public interest throughout the states of Colorado, Utah, Wyoming, and Montana; Kansas, Nebraska, North Dakota, and South Dakota became part of RMNASTT's territory in 2017. Our chapter's mission is to advance the goals of NASTT by increasing education and awareness in the region.

On behalf of the Rocky Mountain Chapter Board of Directors and the Conference Planning Committee, I welcome you to our seventh annual regional conference. We hope your involvement with RMNASTT benefits your mission to create and maintain a better infrastructure for our region.

Structural Manhole Rehabilitation at Denver International Airport

Jeff Maier, PE
C&L Water Solutions, Inc.

(Presented at the 2017 No-Dig Show — Washington, D.C.)

In 2015, Denver International Airport (operated by City and County of Denver – Department of Aviation) embarked on a challenging project to proactively remediate the most corroded manholes within its wastewater system. The airport, the largest in the United States by land area and currently the 15th busiest airport in the world, has over 600 wastewater manholes located throughout the facility. The manholes that were the focus for this project, located west of the airfield along Tower Road, are downstream of a forcemain outfall that discharges wastewater flows from the airport. Flows from the terminal, cargo facilities, aircraft maintenance, flight kitchens, and de-icing operations make up this wastewater effluent stream, combining together to create a very corrosive environment that had significantly impacted the integrity of the concrete structures located downstream of the outfall location.

This particular project, one of several manhole rehabilitation projects that have taken place at the airport since 2013, focused specifically on nine manholes located downstream of the Tower Road forcemain outfall and upstream of the connection to the Metro Wastewater Reclamation District's East 56th Avenue Interceptor. Because of the severely corroded condition of the manholes, only fully structural methods that included open-cut replacement or verifiable, fully structural trenchless rehabilitation would be considered for the project. The design process involved evaluation of a variety of different remediation methods and technologies, and eventually the selection of fully structural composite manhole inserts as the preferred method for rehabilitation. The project was competitively bid in late 2014, and was awarded to C&L Water Solutions, a certified installer of the

Figure 1. Tower Road Manhole Rehabilitation Project Location

fully structural H-20 load rated Sewer Shield Composite Manhole Insert system.

CHALLENGING CONDITIONS ENCOUNTERED

Beginning in 2012, Denver International Airport implemented a comprehensive condition assessment and inspection program tasked with evaluating critical components of its wastewater conveyance system, including their sanitary gravity sewer pipelines, manholes and other structures. The findings of this evaluation were utilized to help prioritize and develop a proactive remediation plan for these facilities in order to address corrosion, infiltration and other operability issues. Through the evaluations, it was determined that some of the most corroded and structurally deficient manholes within the system were located along Tower Road on a 42-inch HDPE pipeline downstream of a forcemain outfall that handles the airport's sewage flows. The nine manholes that were identified for this project, each being 6-foot-diameter and ranging in depth from approximately 15 feet to 30 feet, are located along Tower Road, a busy arterial roadway that serves a number of airport hotels, restaurants and business centers. The criticality of this outfall line and potential difficulty of flow management due to depths and traffic along Tower Road made these manholes ideal candidates for trenchless structural rehabilitation rather than full open-cut replacement.

The manholes selected for rehabilitation as part of this project were experiencing severe concrete deterioration that could be attributed to biogenic sulfide corrosion. In a number of the manholes, inspections revealed more than 4 inches of concrete material loss due to the corrosion that was occurring.

The turbulent nature of the forcemain discharge and unique wastewater chemistry, resulting from a potent mix of domestic, industrial and de-icing components, intensified the corrosion problems within these structures. Additionally, it was determined that the manholes were also experiencing significant infiltration due to high groundwater conditions in the area.

Because of the severity of these problems, conventional manhole rehabilitation methods of lining interior surfaces using semi-structural coating/lining material was not an option. The flow levels in the 42-inch pipeline, along with the 24-hour operation of the airport facilities, also significantly complicated potential options for above-ground flow management for any length of time. The challenges associated with traffic control along Tower Road further restricted the option for using long-term above-ground bypass operations that would be necessary for the duration of construction activities to perform open-cut replacement of the manholes. As the project constraints became more apparent throughout the design process, fully structural trenchless manhole rehabilitation that could capitalize on internal flow management overwhelmingly became the fastest, least disruptive and most cost-effective option.

THE SOLUTION

During the design process, a number of different manhole rehabilitation products and methods were initially considered by the engineer for the Tower Road Manhole Rehabilitation Project. Because of the severe corrosion, the challenging location along a heavily travelled roadway, depth and infiltration issues, and the presence of high wastewater flow levels, finding a verifiable, fully structural rehabilitation solution became the primary focus and ultimately was the approach taken to rehabilitate the nine manholes.

There are three categories that can be used to generally classify the structural strength of various trenchless manhole rehabilitation techniques. With consideration given to the application, products can be categorized as being non-structural, semi-structural or fully structural. Non-structural products and methods do not provide any structural enhancement to the substrate and can include types of paint and thin mil coatings.

Semi-structural options provide some enhancement to the structural condition of the substrate, but the degree of this structural enhancement is generally not quantifiable. Most high-build coating and lining

Figure 2. Manhole condition prior to rehabilitation

products, used on their own, fall into this category and can include epoxies, polyurethanes, poly-ureas, and many cementitious lining materials. Because of the lack of uniform design standards and criteria for manhole rehabilitation products and methods, coatings and linings that rely on an interactive bond to a properly prepared substrate surface can only be considered to be semi-structural or structurally enhancing at this time. The host manhole must still be structurally sound in order to consider using semi-structural methods.

Methods that are considered to be fully structural include prefabricated composite inserts and polymer manhole insert products. In order to be considered truly structural, the product needs to have verifiable and consistent testing data that proves loading capability both vertically and horizontally. Finite Element Analysis (FEA) data and H-20 load rating provide this level of assurance. Criteria used for CIPP lining design (i.e., ASTM F1216) should not be considered a valid design methodology for manhole rehabilitation due to inconsistencies of manhole shape and configuration, hydrostatic pressure variability that is dependent on depth in a vertical application, and other factors.

Given the project constraints and the structural deficiencies identified within the nine manholes on Tower Road, only fully structural rehabilitation solutions were included as part of the final design package. Because of the significant infiltration issues, prefabricated composite manhole inserts became the favored option due to minimal joints and impermeable construction, as well as the ability to install using internal flow management through use of flow-thru plugs (if necessary). Additionally, fully structural prefabricated composite insert products had been used successfully on a number of challenging rehabilitation projects and applications throughout the Denver metro area, including a 52-feet-deep installation at the end of DIA runway 7-25 that was part of a previous project. Having this successful track record throughout the region, as well as experience with a deep and challenging installation on a previous project, DIA and their engineer were confident that the composite inserts would provide the fully structural rehabilitation solution needed for the Tower Road manholes.

COMPOSITE INSERT INSTALLATION

The Tower Road Manhole Rehabilitation Project was advertised for bid in late 2014. C&L Water Solutions, a Colorado-based trenchless contracting firm that specializes in water and wastewater rehabilitation, was awarded the contract. Construction began in Spring 2015 and was completed on schedule and on budget later that summer.

Sewer Shield Composite Inserts were the rehabilitation products selected to successfully accomplish the fully structural rehabilitation of the nine manholes. These H-20 load rated epoxy-fiberglass composite manhole inserts feature a prefabricated mandrel-wound multi-layer construction, and can be produced in sections ranging from 5 feet up to 25 feet in length. The composite inserts can be produced in a 3-layer or 5-layer system, depending on the anticipated application and service conditions. Each comes with its own new cone section, prefabricated for an exact fit on the insert barrel sections.

Figure 3. Composite manhole insert sections prior to installation

The inserts also feature a 98% sulfuric-acid-resistant novolac epoxy internal surface coating (Sewer Shield 100), which is the highest corrosion resistance available in the industry.

Installation of the composite insert system is a multi-step process consisting of the following:

- High-pressure water blasting (5,000 psi+) of all substrate surfaces within the manhole to remove soft and corroded concrete material and other debris. Removal of existing manhole steps.
- Saw cut and removal of existing manhole cone section.
- Abrasive blast bench and channel area to prepare for rebuilding using a combination of high-strength calcium aluminate mortar (applied as needed at a thickness of several inches up to a couple feet). This serves as the structural foundation for the composite insert barrel sections.
- Injection of chemical grout material as needed to control infiltration.
- Composite insert sections lowered into place and set onto the rebuilt bench area.
- All sections placed and subsequently sealed using Sewer Shield 100 epoxy on the joint areas, and sections are "backfilled" using an expansive hydrophobic grout to fill the annular space. An approximate internal diameter reduction of 10% can be anticipated once the insert system is installed in the host manhole. Sewer Shield 100 epoxy is used to coat the entire bench, channel and invert areas, to provide a uniform 98% sulfuric-acid-resistant finish on all exposed surfaces.
- The new, prefabricated cone section is then placed, a new frame and cover is installed, and the final backfill, paving and/or site restoration is performed.
- Throughout the installation process, a comprehensive quality control and inspection protocol is followed. This stringent attention to detail ensures that surface

Figure 4. Completed composite manhole insert rehabilitation installation

preparation and all subsequent steps throughout the installation process are properly followed. Final testing consisted of a comprehensive visual inspection by a National Association of Corrosion Engineers (NACE) CIP Level 3 Certified coating/lining inspector, high-voltage spark testing of all surfaces, and adhesion testing on the bench and channel areas where epoxy coating material was utilized.

Many challenges were encountered throughout the project, mainly due to the hazardous atmospheric environments, depths and significant flows within the manholes. C&L Water Solutions proactively addressed these challenges and also developed innovative safety measures that were recognized and commended by Denver International Airport. As a result, DIA presented C&L Water Solutions with an excellence in safety award at the conclusion of the rehabilitation project.

The Tower Road Manhole Rehabilitation Project successfully and safely remediated nine structurally compromised manholes using the Sewer Shield Composite insert system, a H-20 load rated, fully structural manhole rehabilitation method. The project was completed on time and on budget by C&L Water Solutions, a licensed installer of Sewer Shield products in the region.

By utilizing fully structural trenchless manhole rehabilitation instead of costly and disruptive open-cut excavation and replacement to solve the corrosion and infiltration problems, the airport saved a significant amount of money and shortened the construction schedule dramatically. Any wastewater flow management that was necessary was able to be performed internally rather than using above-ground bypass methods that would likely have been needed for open-cut replacement, further minimizing disruption to the public and system operations.

The Sewer Shield fully structural composite insert system provides DIA with a 50- to 100-year rehabilitation solution for critical manholes and will help ensure reliable operation of the airport's wastewater infrastructure for many years to come.

Guided Boring Innovation for Longer Lengths, Extended Diameters and Non-Displaceable Geology

Laura Anderson
Director of Marketing
Akkerman Inc.

Akkerman began manufacturing guided boring systems in 2001, and since then the pace for innovation within the technology group has been swift, dramatically increasing the expectations for the average length of sewer, water and utility installations in harder geology.

Contractors are finding fewer instances where they have the luxury to perform an unguided bore, and often project specifications require an accurate grade with narrow easements and tight tolerances.

Nowadays, our complex sub-surface utility landscape demands that new pipe installations take place on average 15-25 feet deep, below buried utilities in much denser ground conditions.

With the advent of enhanced digital camera technology and clarity, it is now possible to see the guidance system's target at a greater distance. Line and grade is maintained within a quarter of an inch at distances of approximately 400 linear feet with the Akkerman GBM guidance system. Given ideal conditions, distances of well over 500 LF are regularly achieved with the same level of accuracy.

Guided boring is desirable to contractors because of the system's versatility for a range of pipe, pipe diameters and geology, the quick set-up time, the small footprint that it requires, and ease of use with minimal crew training. Guided boring also offers lower operating costs and quick production rates, making it a cost-effective solution.

THREE-STEP METHOD

Guided boring is a multi-step process for pipe installation that begins with a launch shaft and ends with a reception shaft for tooling retrieval, and involves a pilot tube installation and guidance system to achieve an accurate line and grade. The second step introduces temporary casings and augers for soil removal, and the third step adds tooling to increase the diameter of the bore and further excavate the soil.

When the launch and reception shafts are excavated and shored, the shaft floor is installed at the alignment's line and grade and the jacking frame is lowered into place.

The lead pilot tube adapter features an affixed steering head, selected based on its compatibility with the project's ground conditions. Akkerman dual-wall pilot tubes allow for fluid passage to the steering head through a 1.3-inch outside ring and visibility of the guidance system's illuminated target in the 2.8-inch inner chamber. When pilot tubes are connected, o-rings prevent water from entering the inner chamber and a corrosion-resistant coating helps to maintain visibility of the target. A contractors' inventory of pilot tubes generally sees thousands of feet of use, since Akkerman pilot tubes' joints are designed to withstand up to 10,500 foot pounds of rotational torque. Pilot tubes are provided on racks containing 12 or 40 pilot tubes, enough for 30 or 100 feet.

The theodolite with a camera on the telescope is positioned between the jacking frame cylinders to site-down the center of the pilot tubes, and the theodolite's crosshairs are set to the drive's line and grade. The guidance system monitor assembly is inserted in the monitor mount on the jacking frame valve cover and adjusted to view the illuminated target.

After the steering head and adapter are launched, pilot tubes installation commences. As the operator advances each length of pilot tube, a new segment is threaded onto the former and pushed forward by the jacking frame's hydraulic cylinders. Lubrication flows through the string of pilot tubes to a steering head port on the opposite side of the bill.

While pilot tube advancement is happen-

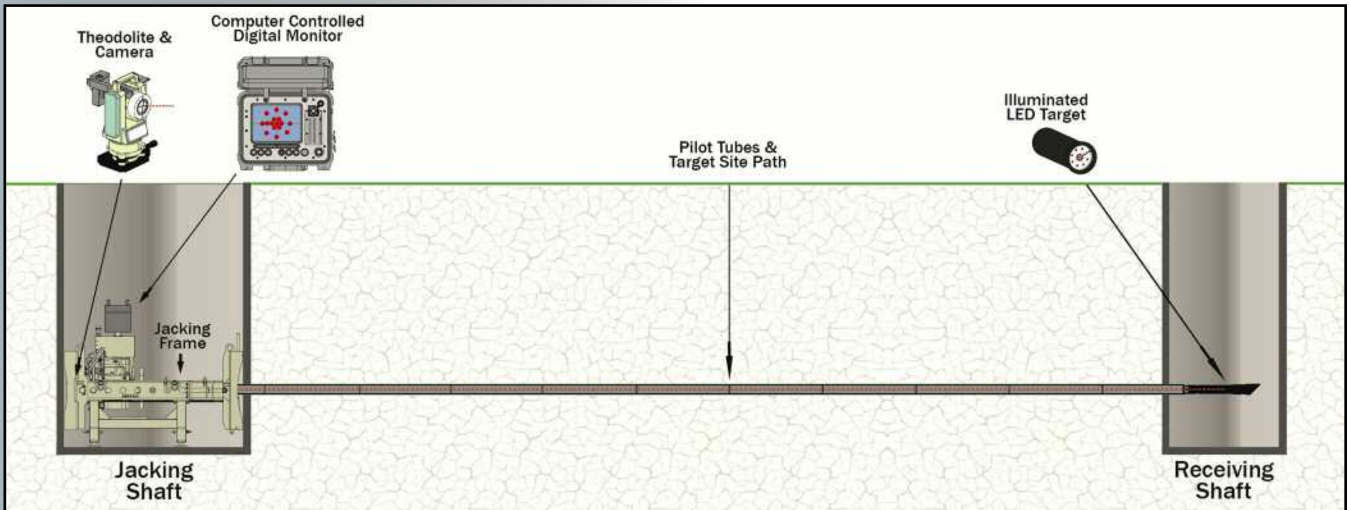

Figure 1. Step One: Installation of pilot tubes on line and grade

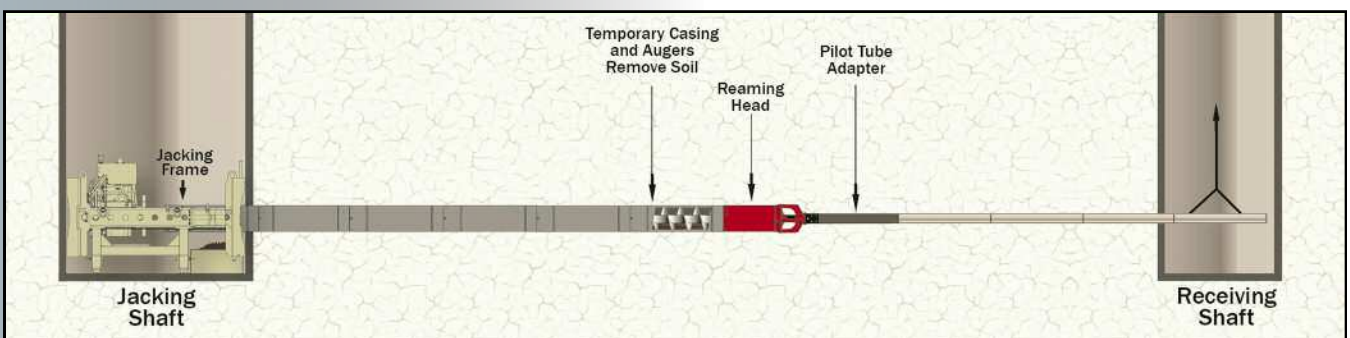

Figure 2. Step Two: Launch reaming head or swivel with temporary casings and augers for soil removal

ing, the operator concurrently assesses the illuminated target's position on the monitor to keep the pilot tube string on line and grade (Figure 1). If an adjustment is necessary, the operator turns the pilot tube string in the appropriate direction. The forward advancement from the jacking frame gear box and rotation of the angled steering head displaces the ground until the correct alignment is achieved. While this sequence unfolds, operators make notes of changes in jacking forces to prepare them for what to expect during the casing installation. Pilot tube installation is complete when the steering head reaches the reception shaft.

During the second step, the pilot tube string is connected to either a reaming head or swivel (Figure 2) and temporary casings with augers. As casings with augers are added to the tooling string, sections of pilot tubes are removed from the reception shaft. Excavated soil travels through the augers to the launch shaft for removal. Step 2 is complete when the temporary casings and augers have reached the reception shaft.

The goal with the third step is to complete the alignment with the final product pipe. A pipe adapter is used in easily displaceable soils, but most often, increase tool-

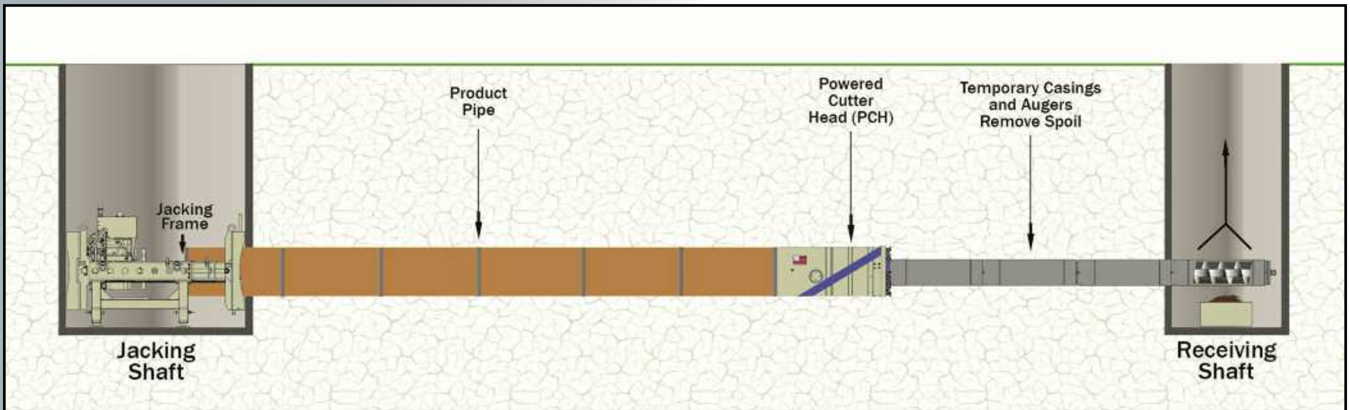

Figure 3. Step Three: Launch increase tooling followed by final product pipe

ing such as a powered cutter head or powered reaming head is positioned in advance of the final product pipe (Figure 3). The augers are then reversed and soils are directed to the reception shaft. The increase tooling's lubrication lines assist in reducing jacking forces in difficult ground.

As the product pipe is added and advanced, sections of temporary casings and augers progress to the reception shaft for removal. The full alignment is complete when the increase tooling reaches the reception shaft and the pipe is completely installed on line and grade.

JACKING FRAME CONFIGURATIONS

The range of jacking frames on the market has made it possible for contractors to jack pipe from a minimum eight-foot shaft with one frame and mimic the powerful capabilities of an auger boring machine to directly install up to 42-inch steel casing pipe with another.

Akkerman's GBM 240A Jacking Frame features a 48-inch stroke cylinder, a universal auger boring machine adapter, and a stand-alone base for fitting the frame within an eight-by-12-foot trenchbox shaft. This jacking frame can install up to 24-inch maximum outside diameter pipe in minimum one-meter lengths with 100 tons of jacking force, 50 tons of pullback force and 10,500 foot pounds of rotational torque.

The GBM 308/339A jacking frames install up to 31.5-inch maximum outside diameter pipe in one-meter lengths from an eight- or nine-foot round shaft. This jacking frame also features a 10.5-inch stroke cylinder, 100 tons of jacking force, 50 tons of pullback force with 10,500 foot pounds of rotational torque.

The 4800 Series Jacking Frame is used to install up to 48-inch pipe from a minimum 11-foot shaft with 265 tons of jacking force, 100 tons of pullback force and 26,000 foot pounds of rotational torque. This frame can install a one-meter to twenty-foot-length pipe, or longer with skid extensions. The 4800 jacking frame is capable of auger boring applications when paired with tooling like a master push ring to manage soil discharge.

GUIDED AUGER BORING

Guided auger boring is defined as the method of accurately installing pipelines using a guided boring system for an accurate pilot tube installation, and the final pipe installation is completed with conventional

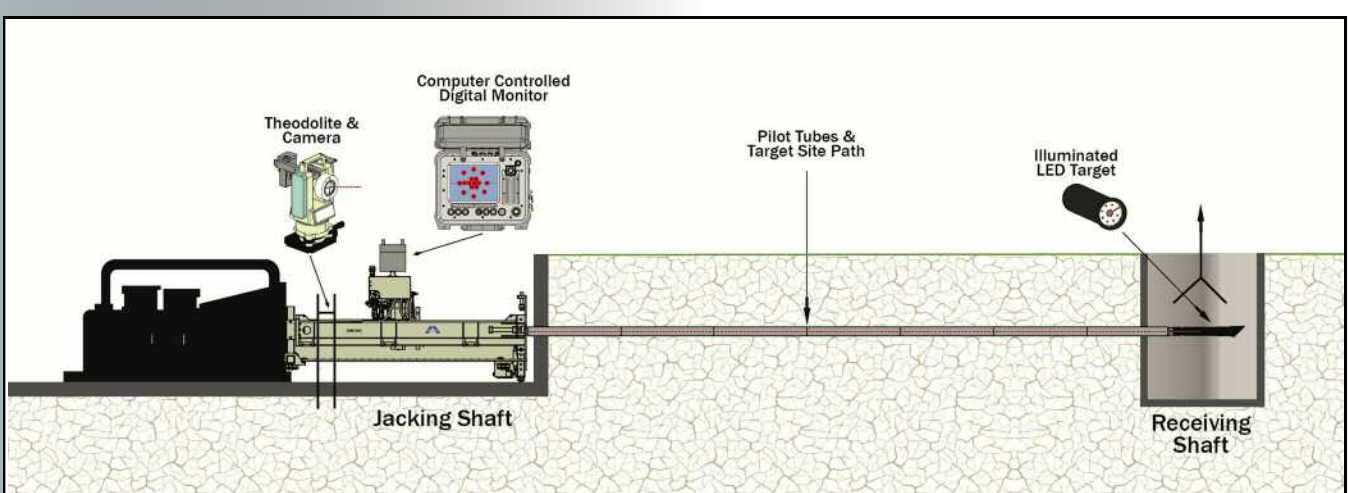

Figure 4. Guided Auger Boring: installation of pilot tubes on line and grade

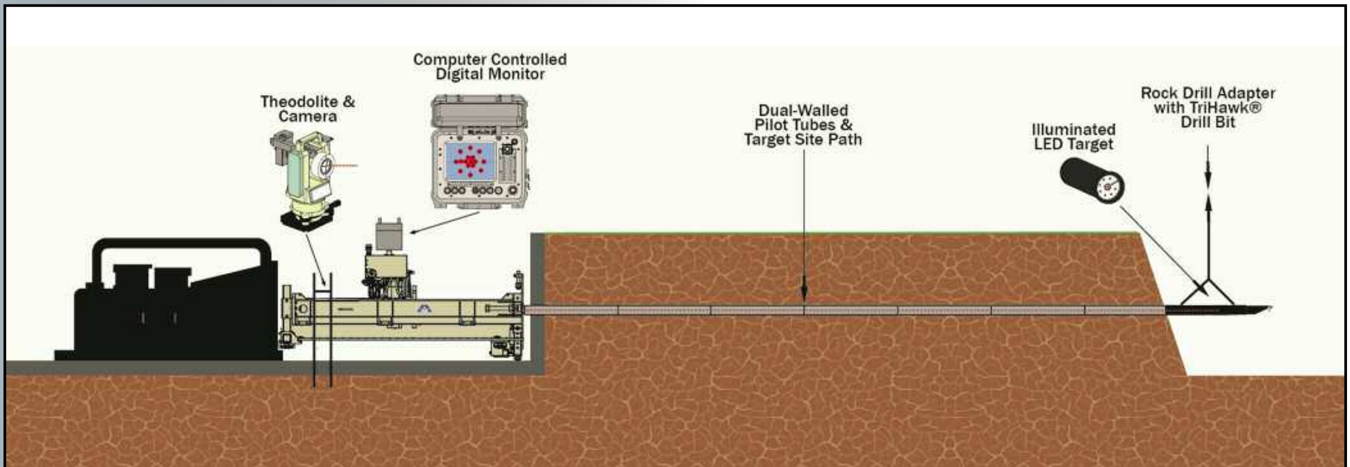

Figure 5. The Rock Drill Adapter (RDA) adapts to TriHawk® drill bits to lead the installation of pilot tubes in up to 18,000 psi UCS ground conditions.

auger boring techniques.

For this method, the GBM 240A Jacking Frame is placed at the front-most position on the auger bore track using the universal adapter, closest to the shaft wall bore entrance point at the appropriate centerline and survey's grade. The auger boring machine is installed and secured on the track directly behind the GBM 240A jacking frame and serves as a backstop when the other unit is installing pilot tubes.

A guidance mounting stand is used to suspend the theodolite between the jacking frames' thrust cylinders on line and grade (see Figure 4). Pilot tube installation commences as described previously.

When complete, the pilot tubes have established a path for subsequent tooling and pipe installation with the auger boring machine. A pilot tube adapter and increase tooling are directly connected to the last pilot tube to increase the diameter of the bore to match the steel casing diameter. The guidance system and GBM jacking frame are removed from the launch shaft and the auger boring machine is repositioned on the track to accommodate the steel casing and tooling lengths.

IN NON-DISPLACEABLE GEOLOGY

For a long time, displaceable soil with an N value less than 50 was considered the safe ground for guided boring. Since 2014, however, new tooling innovation has made it possible to tackle projects in non-displaceable geological profiles up to 18,000 psi unconfined compressive strength (UCS). Non-displaceable tooling options are designed for guided boring as well as guided auger boring.

A notable guided boring innovation is pilot tube rock drilling, which has achieved success in up to 15,000-psi rock conditions using the Rock Drill Adapter (RDA) and a TriHawk® drill bit for densely compacted soils and soft rock like clay stone, stone, limestone, and shale. This method is similar to a standard pilot tube installation, but a drill bit is used instead of a steering head and the RDA houses the guidance system's LED target. Steering control with the RDA and drill is managed with much lower thrust pressures than a standard pilot tube installation. The GBM 240A Jacking Frame is equipped with an RDA jacking pressure control assembly to manage thrust pressures and pilot tube advancement is maintained in a clockwise motion to prevent the pilot tubes from unthreading.

The first RDA and TriHawk® project

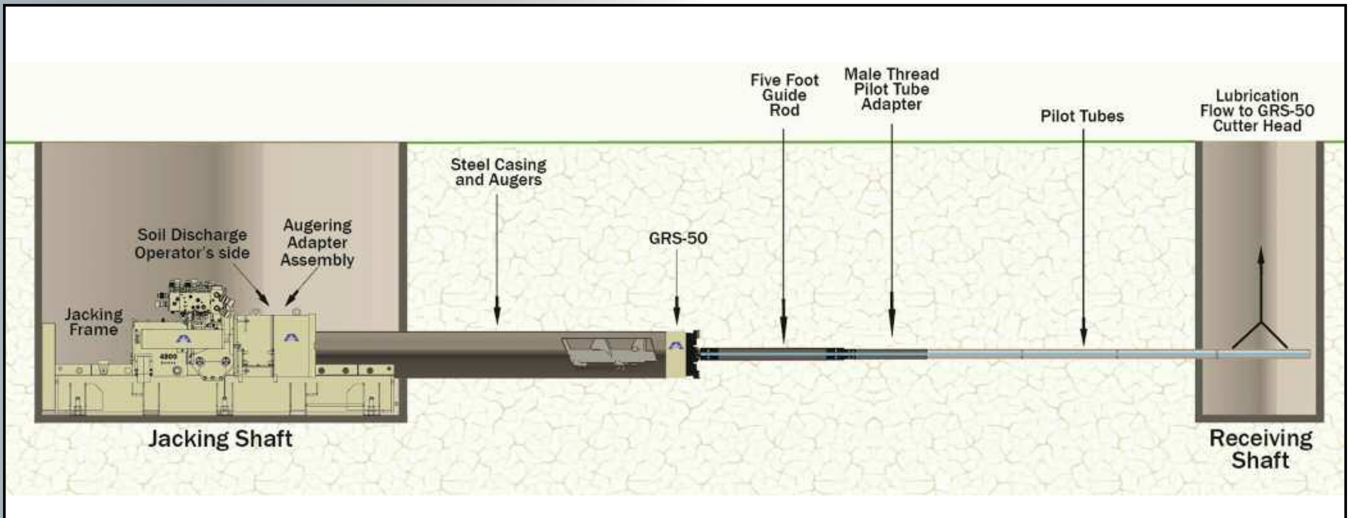

Figure 6. The Guide Rod Swivel 50 is a bearing swivel, cutter head and guide rod combined.

took place in September 2015 on a guided auger boring project in Darwin, Australia, for a 83-LF foot bore. Since then thousands of feet have been achieved. Recently a 327-LF run for a sanitary sewer took place in Greeley, Colorado. The longest installation to date is 400 LF on a project in Bakersfield, California.

Instrumental to the successful operation with the RDA is the continuous use of a bentonite polymer to cool the drill bit and provide enough viscosity to suspend and carry the cuttings away from the face of the bore. Lubrication travels through the annular space in the pilot tube, then out through the drill bit port where it mixes with the cuttings that flush back to the launch shaft. Contractors should consult with a mud supplier at the onset of the project for mud recommendations.

Also new to the non-displaceable market is the Guide Rod Swivel (GRS) 50 (see Figure 6). It is a universal bearing swivel that connects to the auger string with various sizes of interchangeable cutter heads that match common pipe diameters and a pilot tube guide rod combined. The assembly can withstands up to 50 tons of continuous thrust to excavate stiff and difficult ground and features a cutter head with retractable wings. Lubrication is run from the reception shaft through the tooling to flush the cutter head.

The newest increase tooling, designed for up to 25,000-psi rock and 42-inch steel casing is the Rock Boring Unit (RBU). Disc cutters on the face excavate rock for up to 90,000 foot pound thrust loads. It connects to the lead auger with a four-inch hex connection. Cutter face paddles move soil through the assembly to the augers for removal. The RBU follows a pilot tube for up to 18,000 psi UCS with a RDA and drill bit or can be used unguided and advanced with an auger boring machine by inserting the RBU's full-face disc cutter insert for up to 25,000 psi UCS rock.

HYBRID METHODS

Contractor ingenuity has brought about several unique guided boring methods, including guided pipe ramming, pipe roofing, and gas line, fiber optic cable and HDPE and PVC pullback installations.

Guided pipe ramming was first conducted in 2006 on a rescue project in Farmington, Utah, to install 60-inch casing between railroad tracks and has since become a standard service offering for several contractors. Guided pipe ramming is the guided auger boring method of accurately installing pilot tubes to establish line and grade which are followed by a pneumatic pipe hammer, attached to the product pipe. The hammer transfers force to the open-ended pipe to advance it with repetitive percussive blows. Contractors like this method because the pneumatic hammer ensures ground control at the face of the excavation, and since advancement happens so quickly, the potential for settlement is very minimal. This method is also ideal for use in difficult ground conditions, since large boulders are enveloped inside the steel casing.

Guided pipe roofing is used for short tunnels, culverts or crossing for extra reinforcement on crossings in heavily traversed regions for stress distribution and to mitigate ground settlement. Interconnected lengths of steel casing provide an arch above a support structure, culvert or tunnel. Pilot tubes are first successively installed to form the arch on line and grade. The GBM jacking frame is positioned on an adjustable platform to relocate the point of entry for each pilot tube pass. The passes are usually finished with steel casing installations by an auger boring machine but depending on the pipe diameter and ground conditions, the GBM jacking frame can be used as a stand-alone system to complete the steel casing passes as well. The casing arch is filled with concrete and rebar and soil improvement is inserted around the

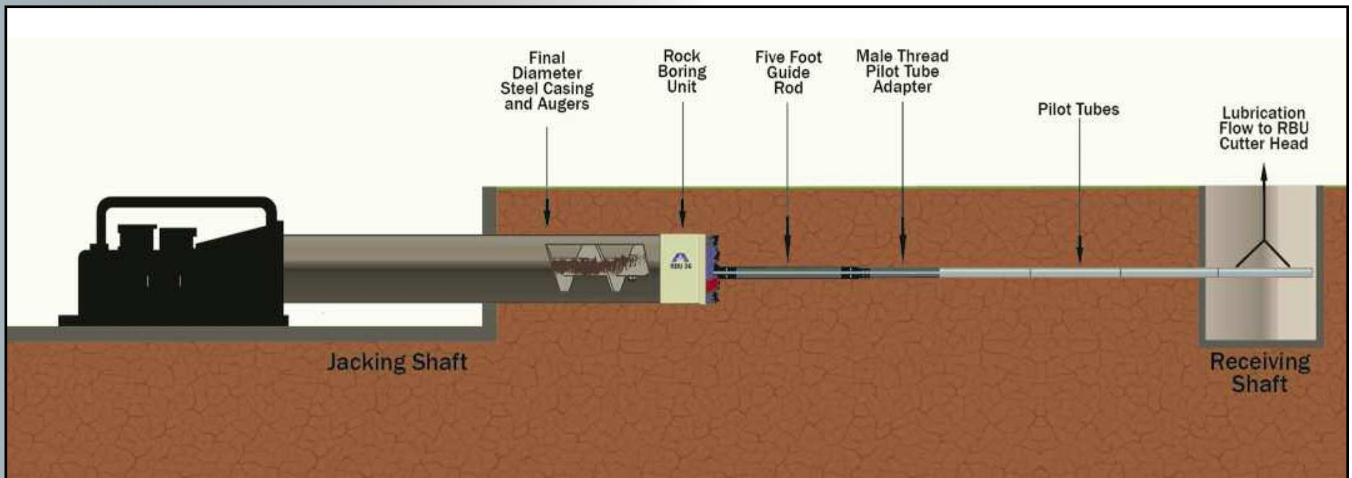

Figure 7. The Rock Boring Unit excavates up to 42-inch diameters in rock.

outside of the structure.

With a utility pullback, the guided boring system is used to install the pilot tube followed by a carrier pipe installation by pullback of fiber optic, cable, gas line PVC or HDPE pipe. This method works in low blow count displaceable soil using up to 11-inch tooling. After the pilot tubes are inserted to length an expander tool, sized to the correct diameter connects to the product pipe with a link with swivel. The expander displaces the additional diameter soil as the jacking frame retracts the pilot tubes while pulling back the pipe.

Guided boring has positively changed the small-diameter trenchless market, allowing contractors to bid new projects and enter the trenchless realm. It's also fair to say that the guided boring equipment sector has seen the most significant amount of development of any trenchless market in a short period of time. Contractors, engineers and municipalities can expect that future guided boring innovation will continue to increase length of bores and expand the range of tooling for even harder rock and larger diameters.

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Bellvue Transmission Pipeline Tunnels:

Challenging Construction in Dipping Bedrock

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Robin Dornfest, PG
Lithos Engineering

Dan Moore, PE
City of Greeley

Nick Jencopale
Southland Contracting, Inc.

Daniel Rice, PE
Providence Infrastructure Consultants

The Bellvue Transmission Pipeline project in northern Colorado was initiated in 2002 by the City of Greeley (City) to meet the anticipated increase in water supply demand in the near future. The concept of the project was to construct a 28-mile-long waterline from the Bellvue Treatment Plant to the Gold Hill Reservoir in order to supplement the current water transmission pipelines owned by the City. In order to do this, the City divided the Bellvue Transmission Pipeline into five segments. The Northern Segment was further divided into two phases. Phase II of the Northern Segment is located in LaPorte (northwest of Fort Collins) and was completed from April 2016 to August 2017 at a cost of $11.6 million. Providence Infrastructure Consultants was the lead design engineer. Lithos Engineering provided tunnel construction management for the City. Southland Contracting was the tunnel contractor.

Phase II of the Northern Segment had a length spanning 5,300 linear feet encountering several physical obstacles along the alignment. One of the major physical obstacles that crossed through the alignment was a large ridge or "hogback" primarily consisting of resistant sandstone. Additional major obstacles included The Cache la Poudre River as well as the irrigation ditches of the New Mercer Ditch and the Larimer County Canal. Furthermore, the alignment intersected a protected historic railroad. These physical obstacles created the need to conduct a thorough subsurface investigation that would present the City with geotechnical baselines through a geotechnical baseline report (GBR) as well as recommended construction methods. Based on the geotechnical baselines and construction recommendations, the design team ultimately decided upon a combination of a tunneled and open-cut alignment. The following sections more thoroughly describe the subsurface investigation, design and construction, as well as challenges and lessons learned.

INVESTIGATION

The subsurface investigation was conducted from March 2015 through June 2015 by Brierley Associates and consisted of 11 borings, three test pits, and one geophysical survey by Olsson Engineering. The borings extended from 50 to 137 feet below ground surface and primarily focused on identifying soil and rock classifications, especially in the hogback which consists of several layers of varying rock. The test pits extended to a depth of 11 to 12.5 feet below ground surface. The geophysical survey extended 930 linear feet along the length of a proposed tunnel location.

The subsurface investigation revealed that the East-West Tunnel alignment was going to extend through several different formations (Figure 1). Encountered formations would include the Mowry Shale, South Platte Formation sandstone, South Platte Formation interbedded shale and sandstone, South Platte Formation shale, and Lytle Formation sandstone. Representative samples of these formations were tested for various properties that affect tunnel design, such as unconfined compressive strength, Brazilian tensile strength, and Cerchar Abrasivity Index (CAI). The CAI quantifies the rock abrasivity that is used to evaluate the extent

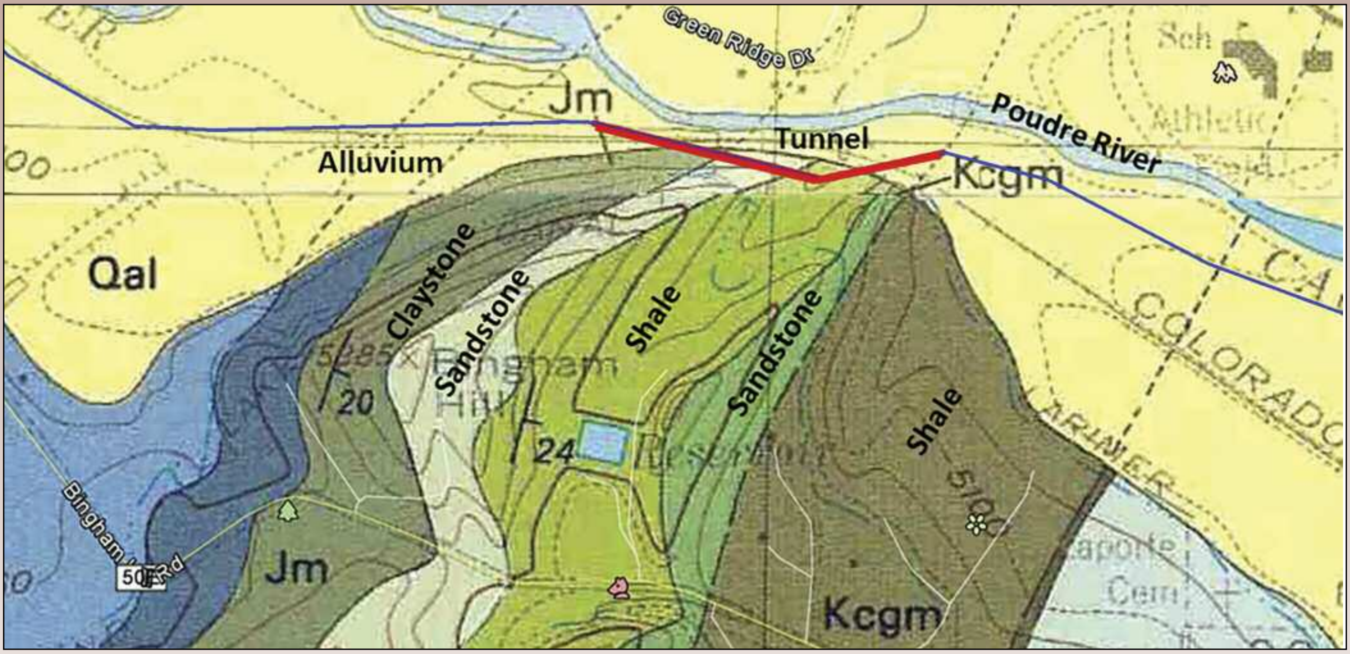

Figure 1. Geologic map of tunnel area (Braddock et al., 1989)

of wear on excavation equipment. The rock formations encountered had compressive strengths ranging from 1,095 psi to 21,481 psi, tensile strengths varying from 92 psi to 1,195 psi, and CAI values of 0.4 to 4.2. The CAI values would be considered non-abrasive to highly abrasive (Cerchar, 1973).

DESIGN AND CONSTRUCTION

As designed, there were to be two straight-line tunnels, an East Tunnel and a West Tunnel, connected by a central shaft. However, the City was interested in seeing how the bids would come in if the contractor was informed that a single tunnel eliminating the central shaft would be considered. Southland Contracting provided an alternative bid eliminating the central shaft and incorporating a curve in the alignment that had a radius of 1,070 feet and a length of 340 feet. The City accepted the low bid cost and was relieved of having to deal with additional surface impacts in the sensitive area near the adjacent railroad grade and a concerned land owner.

To mine the tunnel, Southland selected a custom-built Southland Contracting SS-86-180 86-inch TBM. The TBM was a single-shield design allowing the TBM to thrust off the ribs and lagging with a thrust capacity of 509,000 pounds. The drive systems that gave the TBM its thrust were two 9.1-cubic-inch hydraulic motors capable of 425 foot-pounds at 3,500 psi. For the safety of the tunneling crew, a tail can was attached to the back of the TBM that allowed the crew to assemble each set of ribs and lagging. The cutter head consisted of 12 12-inch and 10 9-inch disc cutters that could operate bi-directionally to control the roll of the TBM. To allow greater excavation capacity before the muck carts would exit the tunnel, a conveyor of approximately 110 feet in length supported by three conveyor gantries was used.

Before the East-West Tunnel was constructed, a horseshoe-shaped tail tunnel approximately 25 feet in length was mined in order to allow the muck carts to switch

Figure 2. Replacement disc cutters

between two rail tracks installed. Following the construction of the tail tunnel, the TBM progressed along the alignment constructing sets of temporary support. Each set of temporary support was 5 feet in length and consisted of 4x13 steel ribs and 3x6 hardwood lagging. At less frequent intervals additional light sets, ventilation conduits, and power cables were installed to keep the tunnel well-lit and ventilated. In order to reduce the length of power cables needed, Southland constructed a gantry for the power unit that would be towed behind the TBM. In order to successfully navigate the curve in the tunnel, Southland used a combination of a pipe laser and a series of refracting lenses. Each refracting lens could alter the path of the pipe laser to a certain angle and as the curve progressed, more refracting lenses would be used in series to complete the turn. From the launch of the TBM to holing through the receiving shaft, it took Southland a total of 147 days to complete the tunnel and construct the initial support.

At the completion of tunnel excavation, Southland installed 60-inch mortar-lined steel pipe with a mortar thickness of 0.5 inches and a steel thickness of 0.25 inches. The installation procedure began at the receiving shaft with a 200-foot test section that would test the grouting method chosen. Grouting from outside the pipeline was encouraged by the City in order to eliminate the need to repair grout ports in the pipeline. The method Southland used to handle water in the annulus was to first dewater as much of the annulus as possible with sacrificial sump pumps. Once the annulus was dewatered, Southland used three grout delivery lines to pump grout into the annulus in three separate lifts; each lift was approximately one-third of the tunnel height. The objective was to seal off the groundwater in the invert from the rest of the annulus to make grouting the following lifts easier. With the combination of the drain tubes in the bulkhead and the sacrificial pumps, grouting of the annulus was successful.

CHALLENGES AND LESSONS LEARNED

From the start of the design, the project team realized that not only would the variable rock formations prove to be a challenge, but the fact that the rock formations dipped at 24 degrees would further complicate tunneling progress. The rock encountered during the tunnel had high compressive strengths and high CAI values. Furthermore, tunneling against the dipping bedrock of the hogback provided an additional challenge of keeping the TBM on grade. Due to the difficult tunneling conditions, Southland identified the necessity to pick a cutter-head design that would facilitate the greatest production. As a result of this, Southland was able to successfully choose a cutter-head design that prevented delays in tunneling progress. This was especially impressive given the wide range of rock strengths encountered.

One notable challenge to overcome was the unfortunate combination of high groundwater inflows combined with an excavation through several very fine-grained rock formations. The high groundwater inflows, in excess of 1,200 GPM, caused the fines from the excavation to not completely settle and eventually travel through the dewatering system. This made it challenging to meet the Colorado Department of Public Health and Environment's suspended solid discharge limit. Southland ended up needing to pass the water through eight 21,000-gallon flat-top settling tanks prior to discharge to the river. Each settling tank had flocculant bags to facilitate the sediment coagulating and settling to the bottom of the tank.

The high groundwater inflows required careful planning to allow for the backfill grouting. In one section where inflows were especially high, the crew attempted to push

Figure 3. Initial buckled pipe damage

Figure 4. Removing damaged casing

some accumulated water out of the tunnel by only pumping grout from the longest delivery line rather than using all three. The sole use of one grout line caused localized pressure to build up along the crown of the pipe which eventually led to a buckling failure of the carrier pipe. Only one 25-foot section of pipe was affected and would need to be repaired.

The solution the team used was to take flexible rolled sections of 0.25-inch-thick steel and compress it to a smaller diameter. Southland would then skid the compressed rolled section through the carrier pipe, decompress the rolled section, and weld it to the existing carrier pipe at the proper diameter. Once the steel repair segments were in place, grout was pumped through the grout ports installed in each repair segment. The repair was successfully completed within 20 working days.

CONCLUSION

Construction of the East-West tunnel encountered some difficult working conditions, primarily because of the water inflows. Fractures in the rock were more connected to the surface aquifer than anticipated in the GBR, allowing for higher water inflow than baselined. The remainder of the GBR accurately reflected the underground conditions, allowing Southland to configure their TBM to mine efficiently through highly variable rock strengths and types. Water inflow combined with claystone bedrock led the challenges with suspended solids in the discharge water. This was overcome using a brute-force method of adding more and more settlement and flocculating tanks until the discharge was within permitted limits.

Buckling of a piece of the carrier pipe was an unfortunate result of attempting to deal with the difficult underground conditions. Luckily, only one pipe segment was affected and the repair effort was able to be implemented quickly and without delay to the project. Despite these challenges, the team persevered through the challenging conditions and successfully completed the project in August 2017.

Figure 5. Repaired pipe section prior to mortar placement

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Eldorado Canyon Mountainside Pressure Pipe Rehabilitation

(Presented at the 2017 No-Dig Show — Washington, D.C.)

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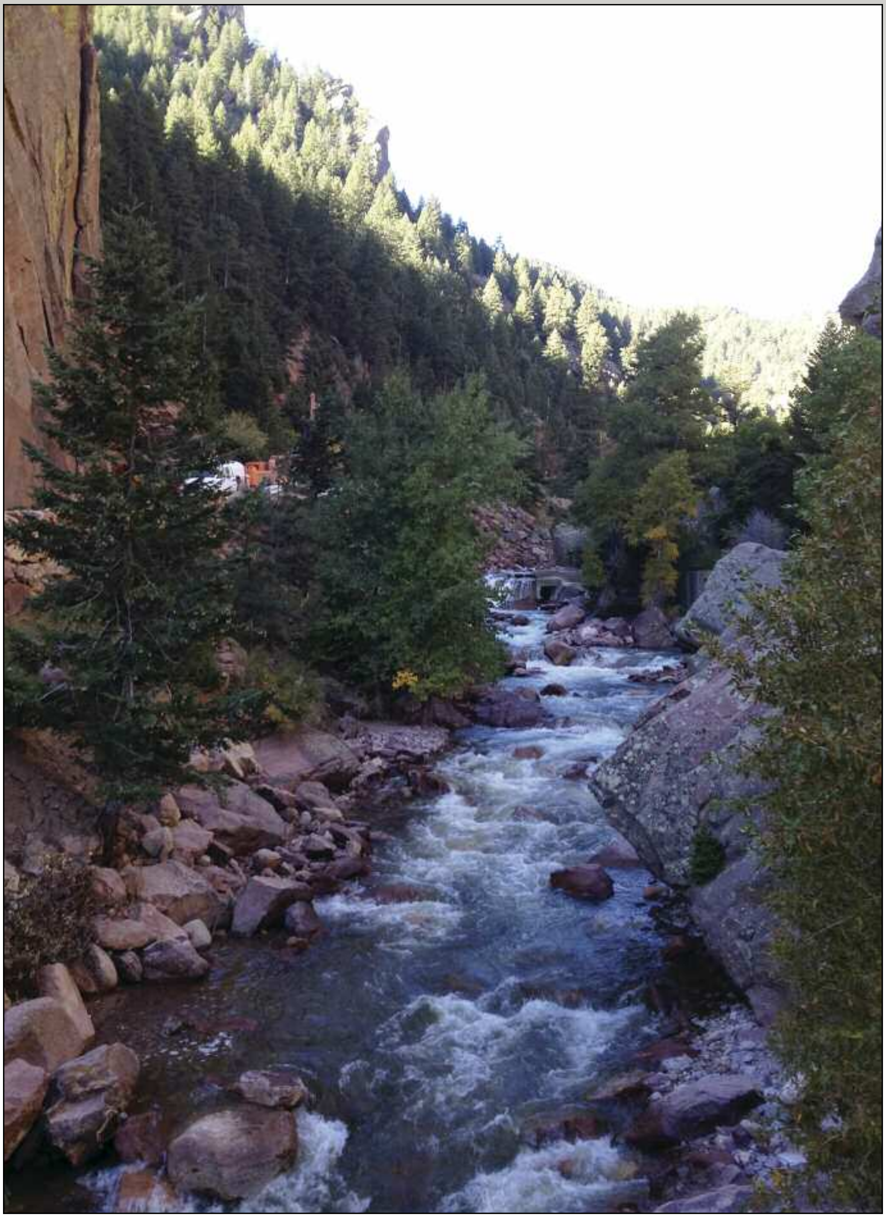
Merrick

Chantal Evans
Insituform Technologies

Brad Dallam, PE
City of Lafayette

The flood of September 2013 came with a fury throughout the state of Colorado. FEMA was quick to act as many Foothill communities and towns were virtually destroyed, with property damages estimated at more than $1 billion. Along with $1 billion in property destruction and the loss of eight lives came a focus on rebuilding damaged or lost infrastructure with an emphasis on sustainability.



Eldorado Canyon's tight confines

Structure compromised from 2013 flood

In the City of Lafayette's case, they own and operate a raw water diversion facility on South Boulder Creek upstream of Eldorado Springs. The facility consists of a diversion structure and approximately 1,200 linear feet of pipeline which diverts water from South Boulder Creek to the Howard Ditch. This water ultimately makes its way to the City's water treatment plant. The diversion structure and pipeline received serious damage in the flood.

Merrick Engineering studied the problem and designed a solution. EZ Excavation served as the prime contractor for the project and subcontracted with Insituform Technologies to rehabilitate the raw water line. This paper will focus on the development of the project, assessment of the infrastructure and specifically on the rehabilitation of the raw water line

The City had been having issues with this facility prior to the flood. One of the primary issues was with boulders and cobbles that would pile up on the diversion face during high flows. Several gates were hard to access and operate when they became buried in these interlocking depositions. The existing facility had a large sediment chamber that was designed to collect sands prior to entering the pipeline. Even with these features, sand routinely was ingested into the pipeline. The pipeline was 12-inch steel and DIP, and there was concern with corrosion and abrasion.

The steel raw water line runs parallel between the mountainside and Boulder Creek. The location of the project, right next to state highway 170 and Boulder Creek, was challenging as it was right up against the rocky walls of the canyon – basically along the side of a mountain. After the 2013 flood, the condition of the facility was assessed. The diversion structure was severely exposed. In addition to being compromised, the pipeline was pitted with pinholes. It was recommended that the diversion structure be completely replaced and the pipeline be rehabilitated or replaced.

DESIGN CONSIDERATIONS

Prior to the flooding, the City was considering rehabilitation of the existing diversion structure. After the flood, this was deemed impractical, and a remove-and-replace approach was pursued. The new diversion structure would need to be designed to manage cobble and sediment loading with screening to prevent sand entering the pipeline. The existing facility had the capacity to divert 1 cfs. The City requested to investigate increasing the capacity of the facility to 7 cfs. This would have required replacing the 12-inch-diameter pipeline with a 16-inch-diameter, and the site was just too restrictive for that. As such, it was decided to rehabilitate the pipeline in place, with a goal to divert the full water right of 3.3 cfs.

The diversion/pipeline system was gravity, but because of the 70 feet of elevation drop, the rehabilitation solution had to be pressure rated. Other considerations for the pipeline rehabilitation included the host pipe being fully deteriorated, so the solution had to be fully structural. The site constraints were severe, so access to the pipeline was minimal. Basically, access was restricted to each end and one point in the middle at the most. The existing pipeline also had several 11-degree bends which were located in areas where excavation was impractical, so the rehabilitation solution had to negotiate these bends.

The engineering analysis looked at sliplining and cured-in-place lining. Sliplining with an 8-inch HDPE pipe would facilitate the 1-cfs capacity, but there was concern over negotiating the bends in the existing steel line. In addition, the City was reluctant to give up capacity even though they would not be able to achieve the proposed 7-cfs capacity. Final plans and specifications were prepared with a CIPP rehabilitation solution. With CIPP rehabilitation, management of sand in the pipeline was critical. As such, the diversion structure was designed with a deep pool at the intake, overshot gates for cobble, gravel and sand sluicing, and a coanda screen at the primary intake.

Insituform's glass-reinforced InsituMain® CIPP product was identified to rehabilitate the water line. This liner is unique in that it is the next generation of Insituform's glass-reinforced InsituMain® product and uses a new specialized glass material. Insituform has had a very focused R&D effort at its headquarters in Chesterfield, Missouri. Significant improvements have been made to the design of the fiber-reinforced CIPP system. The previous pressure pipe product was composed of a layer of non-woven polyester felt, between one and four intermediate layers of triaxial fiberglass fabric, and a polypropylene-coated felt layer.

Replacing the triaxial fiberglass layers in the improved fiber-reinforced product is long

	Old Tube Construction	New Tube Construction
Diameter Range	8" - 12"	6" - 96"
Max Installation Length	900'	2,200'
Flexural Modulus (psi)	600,000	950,000
Flexural Strength (psi)	12,000	35,000
Tensile Strength (psi)	20,000	19,000
Installation Method	Inverted	Inverted
Coating Type	PP	TPU

Table 1. Tube Specification Comparison Chart

CIPP installation hoses suspended over creek

Tight construction footprint for CIPP installation oriented chop (LOC) fiberglass fabric. The unique circumferential expansion capabilities of the LOC fabric provides the ability to manufacture the liner more like conventional CIPP. This eliminates overlaps and provide a tighter fitting, wrinkle-free liner product with better adhesion capabilities. The increased composite strength also facilitates the construction of liners of equivalent strength with fewer layers, thus reducing finished liner thickness.

Another improvement to tube construction is the use of a thermoplastic polyurethane (TPU) coating. TPU coatings help to produce a more robust product that is easily sealable and repairable in both manufacturing and field environments. These and other improvements have improved the scope and range of the current fiber-reinforced liner. (See Table 1)

A provisional patent application has been submitted for the new liner design, which will limit the use of the technology in conventional "inverted" pressure/water CIPP solely to Insituform. Application for U.S. patent assigned serial number 14/861,370 was filed on September 22, 2015. Patent title "Method of Lining Pipe with High Strength Liner, High Strength Liner and Pipe Lined with High Strength Liner" (INSI 4674.US).

Testing of these new products in the lab and the field have yielded excellent results. The list below outlines the improvements this new design offers in contrast to the old tube construction.

- Better expansion capabilities and fit to host pipe (better adhesion)
- Repairable liner coating
- Longer shot lengths
- Increased diameter ranges
- Improved liner flexibility
- Ease of installation
- Reduced layer construction and decreased resin usage (15% less)
- Higher pipe burst strength (up to 1,400 psi)
- Greater composite strength
- E-CR fiberglass for improved long-term corrosion resistance

With these improved benefits, this new liner design presented a variety of benefits to the Eldorado Canyon project.

PROJECT INSTALLATION DETAILS

The project planning was a long process and took more than a year of planning and strategizing with not only USACE and FEMA, but also the Colorado Department of Environmental Quality. While the project was awarded in March 2014, construction did not commence until the second half of 2015.

In addition to the technical and regulatory challenges to this project, the true challenge was working in the restrictive canyon. The contractor had a fair amount of preparatory work ahead of any construction. The contractor cut a temporary roadway into the river bank for access to the structures and then carted over equipment to each structure via an excavator. Insituform then strung out hoses across the river using cabling systems to reach the upstream installation point, which was an extremely small jobsite footprint to work with – roughly the size of a standard hiking trail.

When it finally came time for installation of the pressure CIPP in late December 2015, a massive snowstorm came in and sent blowing snow and 10-degree temperatures through the canyon. The weather made installation especially difficult, but the Insituform crew prevailed and the installation still went in as planned. The project was split up into two shots, each roughly 600 feet in length; they were installed over a three-day period. The first installation started upstream at the existing sand trap structure. The access to the first shot required a temporary road to be built over Boulder Creek from Highway 170 to the first installation site. Most equipment had to be craned over the river from the road using heavy equipment.

In order to do the second shot, an intermediate pit had to be dug for the CIPP installation. This second shot was fast due to the extreme drop in elevation, but had to be carefully done as it had a number of 11-degree bends down the line.

The CIPP portion of the project was completed in three days in December 2015 and completed to the client's satisfaction. It should be noted that after the facility was put in service, the diversion structure and pipeline tested at just over 5 cfs – not the 7 cfs that the client originally wanted, but well over the 3.3-cfs design criteria.

The combination of difficult project location, a broad project team consisting of multiple government entities, contractors and engineers, inclement weather and the use of a next-generation pressure pipe solution all contributed to making the Eldorado Springs pressure project award-worthy, and it was named Runner-Up Rehabilitation Project of the Year by Trenchless Technology magazine in October 2016.

(The authors acknowledge the assistance/consultation of the City of Lafayette's Melanie Asquith.)

Aqua-Pipe Lining Rehabilitation in Loveland, Colorado

(Presented at the 2017 No-Dig Show — Washington, D.C.)

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City of Loveland

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The City of Loveland, not unlike many other municipalities, is increasingly having to determine how to maintain quality service in the face of aging infrastructure that is failing at increasing rates. The realities of this challenge have been recognized by staff, and steps are being taken to implement sustainable funding mechanisms and engineering solutions to ensure quality services continue.

Loveland is a growing community of approximately 75,000 in northern Colorado. Situated about an hour north of Denver, the City has approximately 25,600 water customers. Its Water Utility has a treatment plant capacity of 38 million gallons per day (MGD) which is conveyed to a 32-square-mile service area through a piping network that totals over 450 miles of water pipe between 2 and 48 inches in diameter. The City has seen degradation in the condition of critical water and wastewater components as the Utility has aged. Perhaps nowhere is that better illustrated than in the water transmission and distribution system where leaks have been reliably tracked for 10-15 years through a work order system.

Loveland's water distribution system isn't substantially different than a lot of water providers' in that the pipe material used can roughly be broken down by the age of installation. Early in the history of the Utility, the predominant material used was cast iron with the occasional small-diameter sections of galvanized steel. Notwithstanding larger-diameter steel transmission mains, around 1970 the use of ductile iron pipe began overtaking the installation of cast iron. Likewise, in the 1990s typical installation in the distribution system began being polyvinyl chloride (PVC) pipe except in special or unique installations. Currently the City's transmission and distribution system is more than 54% PVC, almost 30% cast iron pipe (CIP), almost 8% ductile iron pipe (DIP), and nearly 6% steel. (See Figure 1.)

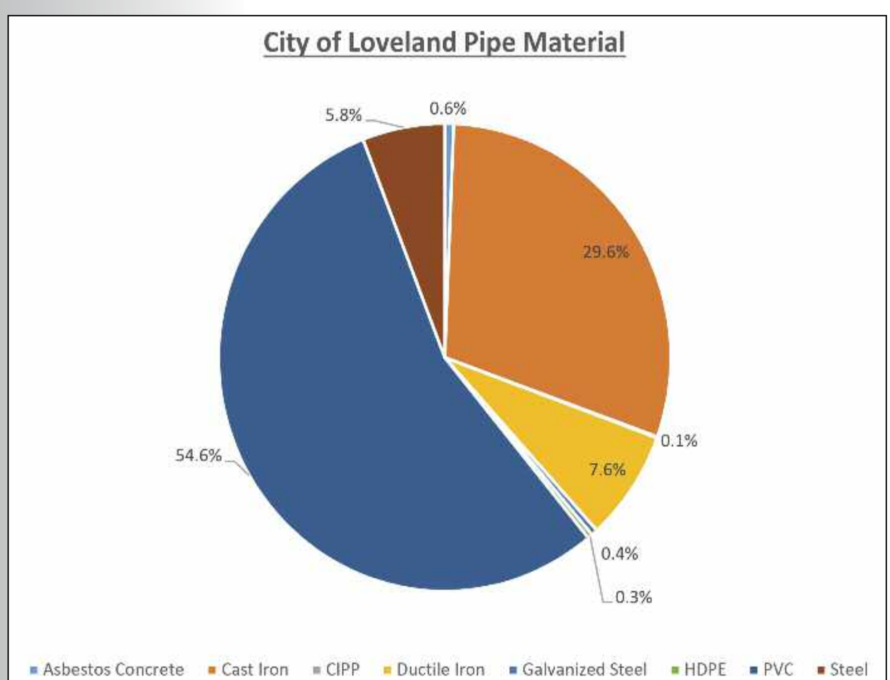

Figure 1. City of Loveland's Pipe Material as a Percentage of Total System Length

Leak History

In the past decade, City staff began ana-

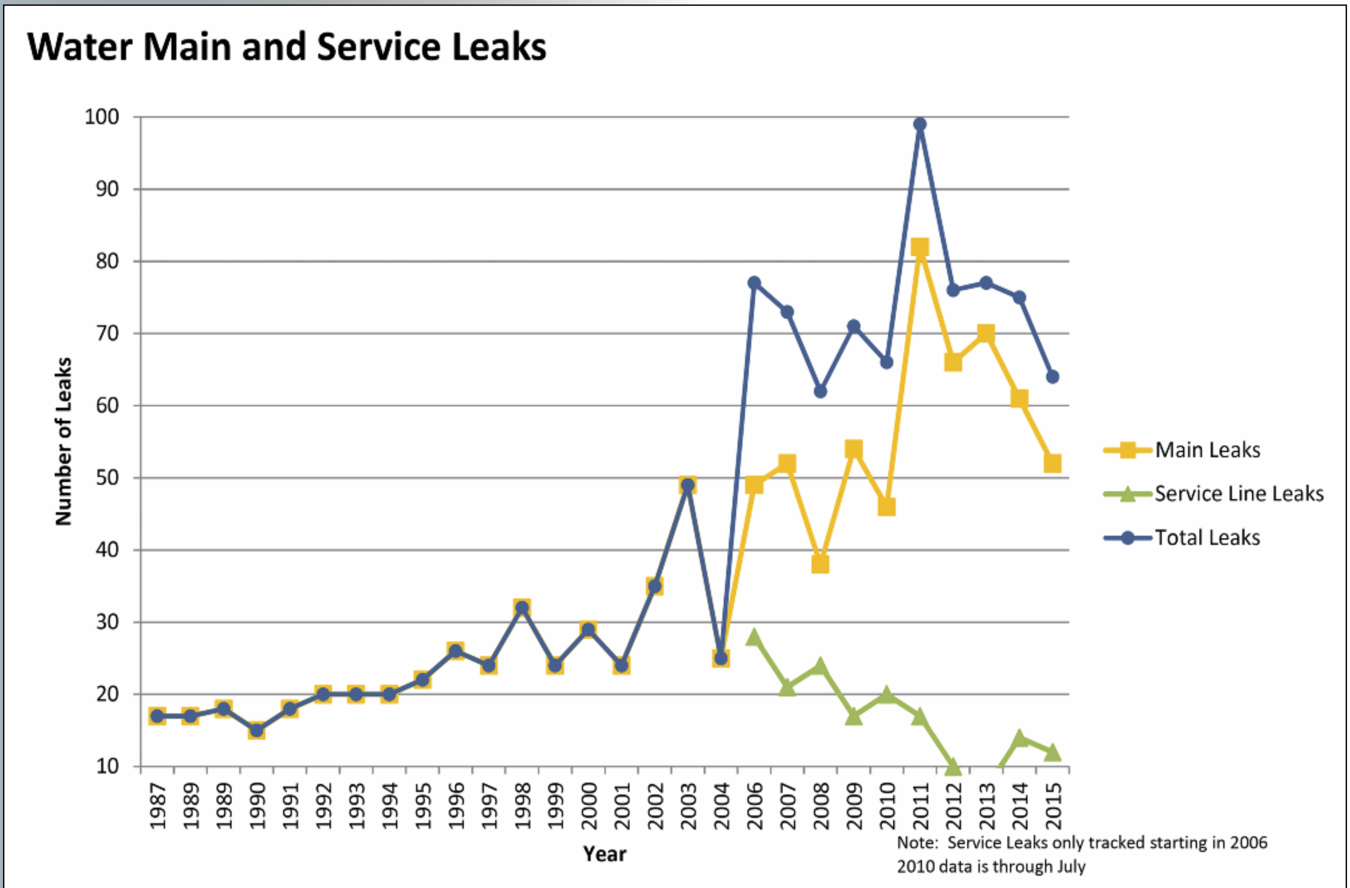

Figure 2. Historical Number of Waterline Leaks

lyzing pipe leak data as a manner in which to judge the health of the distribution system. Observing the significant uptick in water main and service leaks that began around the year 2000 showed a disturbing sign for water managers. Part of the increase could be explained by more accurate record keeping of the number and cost effects of leak repair. With the implementation of an electronic work order system, repair work was better quantified. While the sharp increase in the number of leaks (Figure 2) could be explained, it didn't change the fact that the Department was spending hundreds of thousands of dollars repairing between 50 and 75 leaks per year. Exacerbating the problem was the fact that many of those leaks were recurrent and affecting the same customers repeatedly. Numerous outages to the same customers didn't bode well for the level of service provided. As an example there was a particular neighborhood, constructed in 1979, where crews had been on site for a recorded 20 leaks on 2,000 feet of pipe.

As the number of leaks reached 100 in 2011, efforts were underway to secure additional funding with which to address the problem of waterline replacement. For many years very little capital was invested in the replacement or rehabilitation of water mains. Repairs and decisions were made in a reactive manner. An increase in the Utility rate track was proposed and subsequently approved on the basis that the aging water distribution system needed to be systematically repaired. Based on the needs to rehabilitate water mains and other deferred capital projects, average water rate increases of 10% were approved for a 10-year period. Additionally, funds from the general fund were allocated to replace waterlines that had the highest occurrences of leaks.

At the conclusion of each calendar year, the tracked leaks are quantified and graphically displayed. The number of leaks, the associated repair costs, and the total historical number of outages to customers are used to determine repair waterline rehabilitation priorities for the coming year. The number and costs of leaks are also compared to a "consequence of failure" map for all the waterlines in the system. This map has ranked every pipeline in the system on a scale of 1 to 5 based on effects to customers, potential damage to surrounding infrastructure, and scale of a hypothetical outage. All of this information is combined to form a waterline rehabilitation priority list. Money budgeted for rehabilitation is then utilized to complete projects from the top of the priority list.

A historical review of the sections of pipe that have habitually leaked show that the majority of repairs have been completed on metallic pipes that have suffered from external corrosion. Whether occurring on 2-inch galvanized steel waterlines or 48-inch steel transmission mains, the bulk of time spent on leak repairs has been the result of external corrosion. The vast majority of these leaks are the result of poor installation practices or the lack of cathodic protection. Excavations along the larger-diameter transmission mains show that pipe installed prior to the 1980s was bedded with native backfill. This often resulted in rock or river cobble damaging exterior coatings during installation and resulting in localized corrosion. Likewise, installations of 24-inch and smaller diameter ductile iron pipe were often bedded and backfilled with native material and often not polyethylene encased. Resulting corrosion-induced pipe failures have been the results of improper design, a lack of inspection, and poor construction practices. The millions of dollars of pipe rehabilitation money is a sobering reality of trying to make smart design decisions and to provide meaningful inspection services today.

Prior Trenchless Experience

Part of selecting segments of waterline to rehabilitate each year is an examination of variables that affect possible rehabilitation techniques. Associated with this is a look at existing pipeline locations, asphalt locations, and soil conditions, and trying to find the best rehabilitation method for each project. While the City has replaced numerous waterlines through open-cut construction, trenchless alternatives have been considered and implemented as resources to best serve customers.

In the past, the City has used pneumatic pipe bursting to replace waterline in locations where services were limited and costs associated with asphalt cutting and replacement proved to be exceedingly burdensome. Likewise, waterlines have been replaced in parallel alignments using the directional drill methodology to pull through a fully restrained section of pipe. This technology has benefited the City in locations where major highway intersections or water conveyances were crossed. While the City had trenchless waterline experience, it had not completed waterline rehabilitation via cured-in-place pipe (CIPP). The City had extensive experience lining sanitary sewers with CIPP and was interested to learn about the emerging applications in waterlines.

In 2014, the City contracted with Sanexen Water Inc. to complete a pilot project utilizing their Aqua-Pipe water main rehabilitation product. City operations staff would install necessary valves, dig all access pits, and complete tie-ins following the CIPP installation. The pilot project would allow City engineers and operations staff to see the product installed and gauge its effectiveness. Installing the CIPP in the pilot process was enabled by a cost comparison versus typical open-cut construction over the 1,700 feet of 8-inch waterline to be rehabilitated. An open-cut construction estimate (including traffic control, rehabilitation, etc.) was devised from recent bid rates and the CIPP lining (with City crew time and materials factors) proved to be 80% of the cost of open-cut.

The proficiency in bypass water service, the quality of the installation, and minimal disruption to area customers made the pilot project installation very successful. The City was also pleased with the CCTV inspection that occurred following pipe cleaning and after the CIPP installation. Tremendous effort went into cleaning tuberculation out of the host pipe to ensure the maximization of flow area and having a suitable surface to adhere the CIPP to. The cleaned surface allowed the product to adhere to the pipe with a 100% solids epoxy. The epoxy resin which is injected between two flexible woven composite polyester jackets ensures a Class IV structural liner1. The delivered water is not contacted by the epoxy due to the inner jacket being waterproof. Following the installation, the existing water services were drilled out utilizing a robotic camera that inspects the quality of the installation following pressure testing and prior to reinstatement. With the success of the pilot project, the City was ready to issue bid documents for a larger-scale rehabilitation project that could utilize the CIPP rehabilitation technique.

2015 Rehabilitation Project

2015 saw the City having a waterline rehabilitation budget of nearly $2 million. Through the priority-based waterline rehabilitation ranking system, a series of pipeline candidates emerged that were favorable for lining. Of these rehabilitation segments, there were waterline segments particularly well suited for CIPP rehabilitation versus alternative trenchless or conventional methods. Because of this, the CIPP lining methodology when bid against traditional open-cut was 23% cheaper when City street-cut fees were factored in. (In the City of Loveland there is a $2.50/SF fee for cutting asphalt that has been installed five years ago or earlier. Conversely, the fee for asphalt five years and newer that is cut is $7.50/SF.) Due to the savings in the bid, an additional two rehabilitation locations were added to the original five included in the project. Details of some of the rehabilitation areas and the particulars of why the CIPP methodology was successful are detailed below.

Bedrock Subgrade

A subdivision's utilities built in 1973 consisted of 6-inch DIP and had suffered numerous leaks through the years. Operations staff, during repeated repairs, had observed that the waterlines had been laid on top of a shale bedrock layer and backfilled with bedrock fragments chipped out for the installation trench. The lack of bedding around the pipe had resulted in numerous corrosion leaks through the years and significant damage had occurred to local homes.

As rehabilitation methodologies were discussed, the existence of the bedrock layer at standard burial depth added to the complexity and cost of an open-trench installation. Likewise, the design team was unsure and concerned about how a pipe burst of the existing DIP would react. Due to the uncertainties of these other methodologies, the existing waterline was lined via CIPP technology. A series of three lining "shots" was completed with the longest exceeding 800 feet. With temporary water bypass established, inconvenience to local residents was minimized through the lining process which had four launch and receive pits that averaged eight foot by eight foot. Post-lining CCTV revealed a pipe liner with increased flow characteristics that the City envisions reliably serving customers for years to come.

Cut & Pavement Fees

As mentioned earlier, the City Public Works Department has a street-cut fee system where fees are charged to cut an area of asphalt, in addition to the cost to replace the asphalt. Streets that have been paved within the last five years carry a fee of $7.50 /SF and older streets $2.50/SF. This project wound up rehabilitating over 2,000 of 12-inch steel waterline that had experienced numerous costly breaks through the years. The waterline which was located beneath a busy arterial street also had resulted in detrimental effects to traffic each time a corrosion leak appeared. With the street having been repaved within five years, the street-cut fee savings with CIPP lining verse open-cut was over $140,000. These savings led to the City's money going further while also resulting in less surface disturbance than a traditional open-cut replacement.

Deep Installations

The City had an 8-inch waterline loop to a large retirement village that had experienced leaks previously. While the waterline was not beneath a street, it was buried approximately 20 feet from the edge of the building exterior at depths exceeding 15 feet in places. Repairs at this depth, surpassed the City's staff equipment and risk tolerance in the proximity of a three-story building with a significant footer. The particular section of waterline had been in place at a standard five feet of depth and years later had 10 feet of fill placed on top of the existing grade. The resulting waterline had been fixed at a great cost and with significant disruption in the past and was determined to be a significant risk. These factors along with associated surface restoration costs made CIPP a more available option than open-cut construction.

The 200-foot section of pipe was lined with CIPP through two small and unobtrusive access pits. The CIPP technology allowed a segment of pipe that posed a significant risk to the City to be rehabilitated cost-effectively and with minimal disruption to residents located literally feet from the project site.

Railroad Crossings

A segment of waterline that posed perhaps the highest consequence of failure to the City was a 12-inch CIP that bisected two railroad tracks in the heart of Loveland. Making maintenance and potential leak repair more difficult is the topography of the area. The railroad tracks sit 15 feet below the ground on either side of the crossing. An additional challenge at the site was that the line on the west side of the crossing was located in a backyard and routed around the side of a house before running into a nearby street.

Rehabilitation options at the site were complicated by the fact that the existing waterline casing pipe did not extend from right of way to right of way as required by a new utility permit. Given the houses that were in place and the depth of new access pits, installing a new casing pipe was not a viable option. Of concern to the design team were the three vertical 45-degree bends and one horizontal 45-degree bend. Following a review of similar Aqua-Pipe installations and the procurement of a winch capable of pulling forces greater than those expected, the railroad crossing was change-ordered into the project using the funds saved during the bid.

Following valve installation and careful pit preparation on either side of the crossing, the cast iron pipe was cleaned over the course of two days and the pipe was lined. Lining of the pipe took one hour, and the completed CCTV footage showed a clean installation and only minor wrinkling of the liner at the bends. The pull represented a reduction in risk as repairs at the crossing previously had been difficult and required substantial excavation. Additionally the City's existing crossing permit held the City financially responsible for any delay in rail traffic as a result of the waterline.

As Loveland continues the replacement of aging infrastructure there is slated to be an increased emphasis on funding and rehabilitating waterlines that habitually leak. These leaks continue to be costly to repair, an inconvenience to customers, and a significant source of water loss to the Utility. The success of lining waterlines with the Aqua-Pipe product is one fully recognized by the City and ensures that the product will be used as one of many solutions in future rehabilitation efforts.

REFERENCES

1. American Water Works Association (AWWA) (2014), M28 Rehabilitation of Water Mains, Third Edition

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