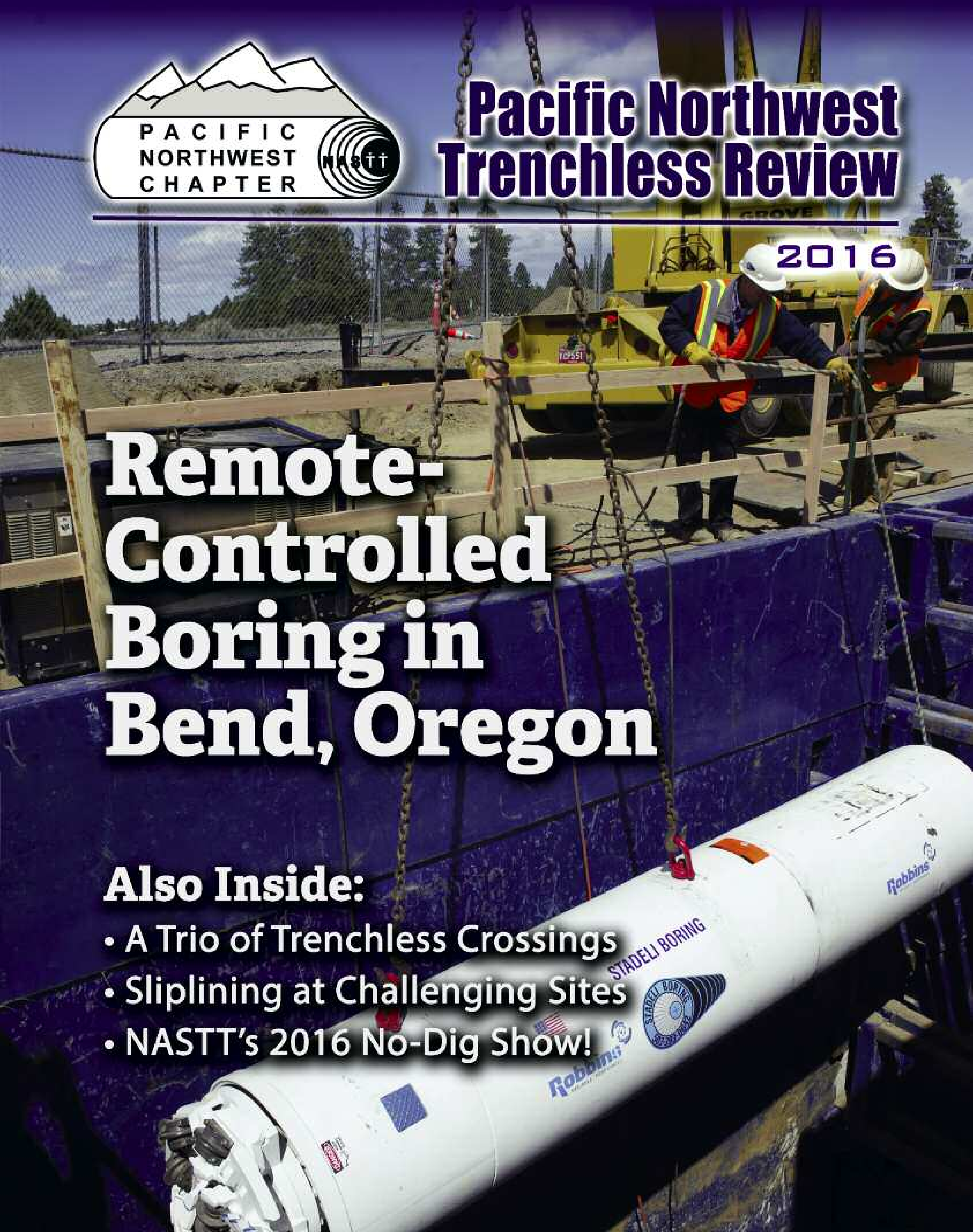
PACIFIC NORTHWEST CHAPTER NASTT

# Pacific Northwest Trenchless Review

2016




# Remote-Controlled Boring in Bend, Oregon

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- A Trio of Trenchless Crossings
- Sliplining at Challenging Sites
- NASTT's 2016 No-Dig Show!

# Pacific Northwest Trenchless Review

PACIFIC NORTHWEST CHAPTER

WINTER 2016

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A prototype remote-controlled small boring unit enabled early completion of a formidable tunnel project

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COVER PHOTO: The Robbins Company


Published by:

PTR COMMUNICATIONS INC.

**Unit 1 – 73 Fontaine Crescent**
**Winnipeg, Manitoba**
**Canada R2J 2H7**





*President*

**Elaine Chouinard**

204.255.6524

elaine@ptrcommunications.com

*Editor*

**Mike Stimpson**

204.231.4707

mike@ptrcommunications.com

*Advertising Sales*

**Tracy Dufresne**

204.837.9176

tracy@ptrcommunications.com

*Layout & Design*

**Lunch Pail Productions**





PTR Communications Inc.
Unit 1 - 73 Fontaine Cres.,
Winnipeg, Manitoba
Canada R2J 2H7

Printed in Canada 12/15

# Change and Opportunity

Chris Sivesind - *Chair, NASTT PNW Chapter*

Winter is upon us, and as 2015 comes to a close I look forward to 2016 and what it will bring for the Pacific Northwest Chapter of the North American Society for Trenchless Technology (PNW-NASTT) and my work as recently appointed chapter chair. Looking back at this year, the word that seems most reflective of the PNW-NASTT's activities is change. Change presents the opportunity to continue growing through education and promotion on the benefits of trenchless technology.

Our former chair, Chris Price, left in 2015 due to a work relocation and the desire to be closer to his family. During his two-year term, Price was dedicated to the board and instrumental in executing an extremely successful PNW Chapter Symposium. I speak for all of our membership in recognizing and thanking Price for his efforts to make the PNW-NASTT chapter stronger in so many ways.

Thanks go to Laura Wetter, former longtime board member and chair, for her service and dedication. Even when her term as chair ended in 2012, she continued to stay involved and attended every meeting. Wetter took the lead in organizing the Pacific Northwest Trenchless Review publication for the past several years. We wish her the best with her new career at Google Fiber and thank her for her dedication to the chapter.

We appointed two new board members and reassigned another board member to the Treasurer position. We had increased interest post-symposium from people wanting to become more involved with PNW-NASTT and NASTT. We welcome new board members Brendan O'Sullivan from Murray Smith & Associates in Portland, Oregon, and Brandon Simonds of Trenchless Construction Services in Arlington, Washington, and look forward to their contributions. We have two at-large board of director positions open. If interested, please contact me or any board member for details.

The 2015 Trenchless Symposium was held at the Cedarbrook Lodge in Seattle this past May. The symposium and trade show were well attended; we had many educational project presentations and 12 vendor booths. Day 2 of the event featured the Pipe Bursting Good Practices short course presented by Drs. Sam Ariaratnam and Collins Orton. We received much positive feedback regarding the instructors and the quality of the information in the short course. Thanks also to all our chapter members for taking time out of their busy schedules to attend this event. The 2017 Trenchless Symposium is scheduled for early 2017.

The Pacific Northwest is a great place to live and work, and our economy is thriving. Our chapter goal for 2016 is to increase membership and participation, particularly outside of the Seattle and Portland metropolitan areas. With all this growth, it will be vital to not only utilize trenchless technology for its numerous benefits, but also create awareness about its inherent benefit of reducing the socioeconomic impacts of other construction methods to residents and businesses. Hosting lunch-and-learns and collaborating with established contractor associations is a great way to further our cause. I welcome your ideas on expanding the PNW-NASTT's reach.

We will have a general membership and board meeting in January 2016; specific details will be available on the website soon (www.pnwnastt.org). Also, mark your calendar for the meeting on Sunday, March 20, in Grapevine, Texas (Dallas) at the 2016 No-Dig Show.

This fall I had the opportunity to attend several of the NASTT chapter events, and all were insightful and well organized and attended. It's impressive to witness the dedication of these chapters' volunteers. I thank Michelle Hill and her team at NASTT for their involvement with the chapters; they are more successful because of her and her team.

Regards,
**Chris Sivesind**
*Chair, NASTT PNW Chapter*

# A Promising Future for NASTT

Kimberlie Staheli - *Chair, NASTT*

Greetings, Pacific Northwest Chapter Members! NASTT is having a great year, and I'm excited for the future of our Society during my term as Chair of the Board of Directors and beyond. As you may be aware, NASTT's 2015 No-Dig Show in Denver was a huge success as we broke attendance records and experienced a sold-out exhibit hall. Personally, I heard a number of excellent presentations and have read numerous quality papers since the show. It is clear that NASTT's No-Dig Show is a mecca for trenchless education, and without a doubt our website (nastt.org) houses the most comprehensive source of trenchless information.

NASTT would never be where we are today without the grassroots support of our volunteers and regional chapters. I would like to take this opportunity to thank the Pacific Northwest Chapter Members who served on NASTT's 2015 No-Dig Show Program Committee: Dan Buonadonna, Jack Burnam, Steven Donovan and Laura Wetter. I'd like to give a special thank-you to Laura Wetter, who also served as a session leader. Serving on the Program Committee is a serious time commitment, a lot of hard work and requires volunteer travel. Without these individuals who believe in the industry and the power of education, the NASTT No-Dig Show could not succeed. Thank you!

One of the goals that the Board of Directors identified through strategic planning is to engage a larger group of trenchless professionals to participate in the many volunteer opportunities provided by NASTT. NASTT has a very 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.

NASTT has a very promising future, and your Pacific Northwest Chapter is stronger than ever. Thank you again for your continued support and dedication to NASTT and the trenchless technology industry.

Sincerely,
**Dr. Kimberlie Staheli**
*Chair, NASTT*

ROCKIN' AUCTION
MARCH 21, 2016

MARCH 21, 2016 | 5:30 PM - 7:30 PM | DALLAS, TX

# NASTT'S 15TH ANNUAL EDUCATIONAL FUND AUCTION AND RECEPTION

**In conjunction with NASTT's No-Dig Show**

**Rock on!** NASTT presents the fundraising social event of the year – the **15th Annual Educational Fund Auction and Reception!** Since 2002, NASTT has raised over $815,000 to support our educational initiatives. Due to your *epic* generosity, NASTT is able to sponsor students' attendance at the No-Dig Show, award scholarships and provide targeted training courses to the membership at-large.

## EXCITING AUCTION ITEMS

Come to the auction and bid on great items like trips, tickets, electronics, industry items and more!

## TROPICAL VACATION RAFFLE

The winner of this raffle will receive a dream tropical vacation, a $5,000 value! Tickets are $25 or five for $100 with a maximum of 1,000 tickets being sold. Don't miss out – preorder your tickets by visiting nastt.org/auction.

Need not be present to win.

## COSTUME CONTEST

Dress like your favorite rock star, past or present!

## 50/50 RAFFLE

A great way to win some cash for yourself and help out our student chapters! The winning ticket will be drawn immediately following the live auction and you must be present to win. The winner splits the cash pot with the students. Dude, it's that easy!

Raffle generously sponsored by Vermeer

Auction Reception sponsored by Interplastic, Miller Pipeline

FOR MORE INFORMATION ABOUT THE AUCTION VISIT:

**NASTT.ORG/AUCTION**

# NASTT Pacific Northwest Chapter

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*Akkerman*
Seattle, Washington
**(507) 567-2261**
csivesind@akkerman.com

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*Trenchless Construction Services LLC*
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Portland, Oregon
Brendan.O'Sullivan@msa-ep.com

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Bothell, Washington
**(425) 205-4930**
matt@stahelitrenchless.com

### Immediate Past Chair
**Erik Waligorski**
*Stantec Consulting*
Bellevue, Washington
**(425) 869-9448**
erik.waligorski@stantec.com

# Coming Events

*January 21, 2016*

**RM-NASTT**
**Utah Training Day**
Larry H. Miller Training Center
(SLCC Campus)
Salt Lake City, Utah
*Information:*
*nastt.org/calendar*

*January 27, 2016*

**NASTT's CIPL**
**Good Practices Course**
PSE&G Edison Training
and Development Center
Edison, New Jersey
*Information:*
*nastt.org/calendar*

*March 20, 2016*

**NASTT's Introduction to**
**Trenchless Technology –**
**Rehabilitation**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

*March 20, 2016*

**NASTT's Introduction to**
**Trenchless Technology –**
**New Installations**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

*March 20-24, 2016*

**NASTT's 2016 No-Dig Show**
Gaylord Texan Hotel & Convention Center
Dallas, Texas
*Information:*
*nodigshow.com*

*March 23, 2016*

**NASTT's Gas Good Practices Course**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

*March 23, 24, 2016*

**NASTT's HDD Good Practices Course**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

*March 23, 24, 2016*

**NASTT's CIPP Good Practices Course**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

*March 23, 24, 2016*

**NASTT's New Installation Methods**
**Good Practices Course**
Gaylord Texan Convention Center
Dallas, Texas
*Information:*
*nastt.org/calendar*

# New Trenchless Boring Method Successful in Oregon Crossing

*In Bend, Oregon, local contractor Stadeli Boring & Tunneling had a unique set of circumstances for a new gravity sewer interceptor designed by engineer CH2M. Stadeli had a contract with general contractor Taylor NW to furnish and install 323 feet of 36-inch steel casing under live railroad tracks. Line and grade were crucial on the project, and the rocky conditions limited their trenchless boring options.*

**Diana Worthen**
***CH2M***

**Desiree Willis**
***The Robbins Company***

**Larry Stadeli**
***Stadeli Boring & Tunneling***

The job required a tunneling system that could handle hard, blocky, abrasive rock, and with a high precision for line and grade, at a small diameter range. This paper discusses the design and successful completion


*The Robbins 36-inch-diameter SBU-RC was launched at a jobsite in Bend, Oregon, for contractor Stadeli Boring & Tunneling in April 2015.*

*The Stadeli crew lines up the SBU-RC in the launch pit to bore a 323-foot-long crossing for a new gravity sewer interceptor.*

of this tunnel using an advanced prototype machine to meet these specific requirements.

### PROJECT BACKGROUND

With its nearby access to mountains, rivers, and pine forests, central Oregon is attracting more residents by the year, and the City of Bend needed to expand its infrastructure to accommodate the growing demand. The City is constructing a new gravity sewer pipeline that will provide service to rapidly developing areas east and southeast of the city's core area.

The pipeline, named the Bend Southeast Interceptor, ranges in diameter from 24 inches to 30 inches and extends about six miles along the eastern edge of the city from the existing plant interceptor in northeast Bend. The alignment includes a 323-foot-long, 36-inch-diameter trenchless crossing of the Burlington Northern Santa Fe (BNSF) railroad in southeast Bend.

The pipeline crosses the railroad tracks at a location where the ground surface adjacent to the railroad transitions from a cut in a surface projection of basalt rock, which is roughly 10 feet high on the west side of the tracks, to a relatively flat open area that is undeveloped on the east side of the tracks.

### GROUND CONDITIONS

During the geotechnical investigation, two exploratory borings were drilled near the crossing alignment, one on either side of the BNSF tracks. Rock was encountered in both borings at 2.5 to four feet below the ground surface, and both borings were completed using rock coring techniques to depths approximately 10 feet below the tunnel alignment. No groundwater was encountered in this investigation. Based on observations from nearby past projects, groundwater in the region is approximately 200 to 400 feet deep, well below the tunnel alignment.

The rock encountered in the borings was hard, gray vesicular basalt with significant void space. The unconfined compressive strength (UCS) of the basalt within the tunnel alignment typically ranged from 3,000 to 5,000 psi; however, it was baselined up to 15,000 psi because of the variability of this rock and the results of UCS tests on rock encountered in nearby borings.

The RQD of the rock encountered within the tunnel horizon was baselined between 70 and 100 percent, and the rock was considered blocky. The abrasivity index of the rock was baselined at 4.0, indicating hard rock abrasiveness. The rock's high strength, high abrasivity, and blocky, void-filled nature were significant features to consider for the design and construction of this tunnel.

### DESIGN CONSIDERATIONS

The 24-inch pipeline crossing of the BNSF tracks was cased using a 36-inch Permalok steel casing pipe to support the tunnel,

*The compact SBU-RC operates using an in-shield drive motor for torque. View shows the inside of the SBU-RC with drive motor.*

meet BNSF requirements, and facilitate installation.

In the absence of groundwater, CH2M required auger boring for the crossing. However, the UCS of the basalt bedrock was considered by machine manufacturers to be too great for excavation by traditional auger boring using conventional rock heads, such as a "Christmas tree" head. Given the gravity nature of the carrier pipe, the control of line and grade was critical for this crossing. The use of a standard small boring unit (SBU-A) or steerable, motorized small boring unit (SBU-M) with disc cutters was required to maintain the design line and grade.

Tunneling contractor Stadeli Boring and Tunneling teamed with The Robbins Company to determine the best machine for the rock conditions and line-and-grade requirements. They felt a typical SBUA or SBUM lacked the precision guidance system needed for dependable results. They selected a Robbins 36-inch prototype machine known as the SBU-RC (for "remote-controlled small boring unit") which had been tested on one job previously in Oman.

The SBU-RC is controlled from an operator's station at the ground surface. It is equipped with a smart guidance system, by TACS, and using pinpoint software the guidance system shows the operator projections of the future bore path so steering corrections can be made in real time to stay on line and grade. An inshield drive motor provides torque to the cutterhead, while a pipejacking frame or standard auger boring machine provides thrust and installs 20foot sections of steel casing pipe behind the SBURC.

Much like other small boring units, the new machine uses a mixed ground cutterhead fitted with 6.5inch disc cutters to efficiently chip rock from the excavation face in the same mechanism used by larger TBMs. And while the SBURC method is


*Spoils are removed from behind the SBU-RC cutterhead directly to the surface using a vacuum truck.*

similar to microtunnel boring machines (MTBM) in many ways, it differs significantly in its spoil removal system. MTBMs require a slurry to pump the spoils back to the surface, and the slurry must be cleaned and treated at a spoils plant, which can be time-consuming, messy, and expensive. In this case, the significant void space and fractures in the rock would have made it difficult to maintain slurry circulation with an MTBM. The SBURC used a vacuum system for muck removal, connecting a vacuum truck to a six-inch suction line, which pulled material to the surface from behind the cutterhead. The launch pit remains clean and dry as the spoils are contained in the vacuum truck.


*The Robbins SBU-RC broke through two weeks ahead of schedule on May 5, 2015. The blocky basalt subsurface conditions are seen here at the exit pit.*

### TUNNEL CONSTRUCTION

Robbins delivered the SBU-RC to the Bend site on April 14, 2015, and Stadeli crews lowered it into a 26foot-deep launch pit. In the beginning stages of tunnel construction, some modifications were made to the system. In the first few feet of tunneling, the crew quickly identified that rock particles larger than four inches could not pass through the vacuum line, and the machine was retracted for modifications to the cutterhead, including grill bars, to restrict the size of the spoils allowed to enter the vacuum system.

As tunneling progressed, the capability of the 4,000-cfm vacuum truck to clear spoils from the line slowly dwindled, until finally at about 100 feet of advancement it was no longer effective and the rock spoils clogged the vacuum line. This truck was replaced with a 6,000-cfm vacuum truck, increasing the suction by 50 percent. After crews replaced the clogged lines, this truck was suitable for the remainder of the 323foot tunnel. Additionally, the new truck had a larger tank capacity, allowing the installation of an entire 20foot casing before the tank had to be emptied, eliminating the need to disconnect the truck and stop production between the placement of casing pipes.

While the cutterhead performed well in the highly abrasive rock, the vacuum line required replacement and repair in several locations, especially at curves in the line. Reducing curves in the line and using abrasiveresistant vacuum pipe materials were important modifications for success.

The machine bored through basalt rock full of fissures, fractures, and rubble pockets between 5,000 and 7,000 psi UCS. While the start-up presented challenges, crews soon achieved rates of 20 feet per day after the modifications to the cutterhead and vacuum system. As the crew became accustomed to the machine, advance rates increased to 40 feet per day, with a record day of 50 feet of advancement. The crew holed through on line and grade two weeks ahead of schedule.

The early tunnel completion delighted the City of Bend and all those involved, as the two weeks saved resulted in cost savings for all parties.

With the SBU-RC success in Oregon, Robbins will now lease the machine for other applicable projects and expand their offerings. The modifications required in Bend will be incorporated on all future models, including cutterhead grill bars, and the requirement for larger vacuum trucks will be communicated to contractors. This project success demonstrated the SBU-RC is the ideal equipment for contractors looking to bore long crossings at small diameter in hard rock or mixed ground, while maintaining strict line and grade control.

# Multiple Grade-Sensitive Pipe Rams in Soft Soils

**Michelle L. Macauley**
Jacobs Engineering Group (Previously with GeoEngineers)
**Anthony Sanich**
Washington State Department of Fish and Wildlife

Three trenchless crossings under State Route 162 (SR 162) were part of a new fish hatchery near Orting, Washington, for the Washington State Department of Fish and Wildlife. The 120-foot-long pipelines were of 24-inch, 30-inch and 48-inch diameter. The 24-inch pipeline is a pressurized water intake pipeline to provide fresh water to the hatchery. The 30-inch pipeline is a gravity return water pipeline, and the 48-inch is a fish ladder for returning adult fish. The 24-inch and the 30-inch pipelines were upsized by the contractor to 30-inch and 36-inch casings, respectively.

The project is located southeast of Orting. Figure 1 shows the project area relative to nearby cities and relative to Mount Rainier (bottom right of the primary image).

Orting is underlain by a series of mudflow deposits from Mount Rainier. The mudflow deposits resulted from rapid mass flowage (and deposition) that was mobilized by water. Because of the rapid deposition, relatively recent mudflow deposits are typically very loose or soft silt and silty sand.

Subsurface soil conditions at the site were evaluated based on two previous geotechnical borings at the WSDOT bridge abutment and four explorations in support of this project. Based on the geotechnical boring, the subsurface soils were expected to be loose to very loose silty sand and sandy silt (mud flow deposits). Test pits indicated soil with good stand-up time (side walls didn't cave) and of minimal groundwater seepage.

The test pits indicated good stand-up time and firm soil above the groundwater table. Depending on the silt and clay content of the soil and the actual groundwater level during construction, the soil could behave as a firm soil or it could behave as a flowing or squeezing soil. Flowing soils could increase the risk of settlement of the highway and loss of grade for the casings. WSDOT, the governing permit agency for the highway, wanted pipe ramming because typically a soil plug forms within the pipe and reduces the risk of settlement.

Figure 2 shows a plan view of the proposed pipelines. The blue line indicates the 36-inch-diameter pressurized intake pipeline, the green line indicates the 48-inch-diameter gravity fish ladder pipeline, and the yellow line indicates the 30-inch

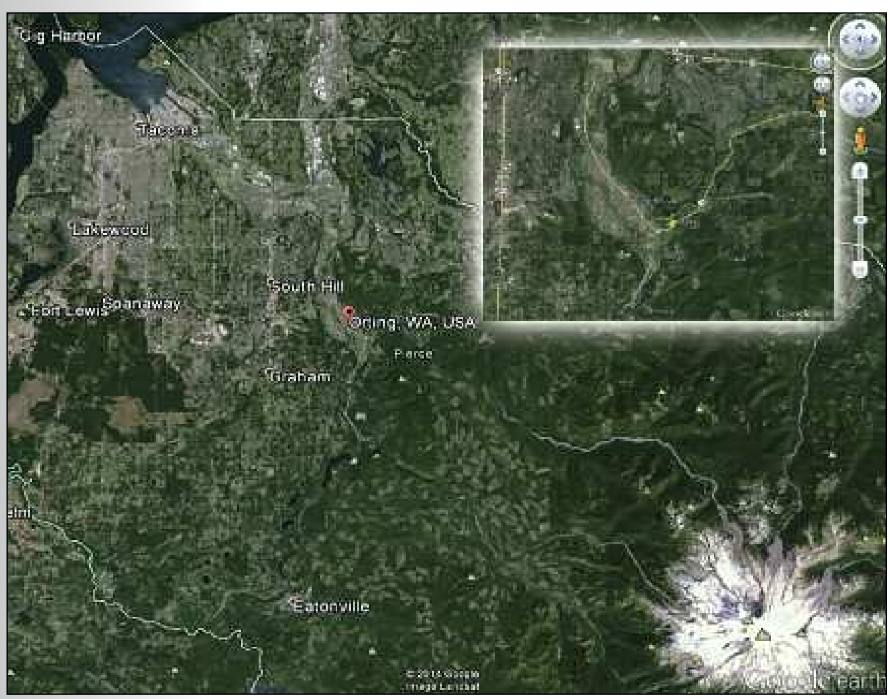



*Figure 1. Vicinity Map of Orting, Washington*

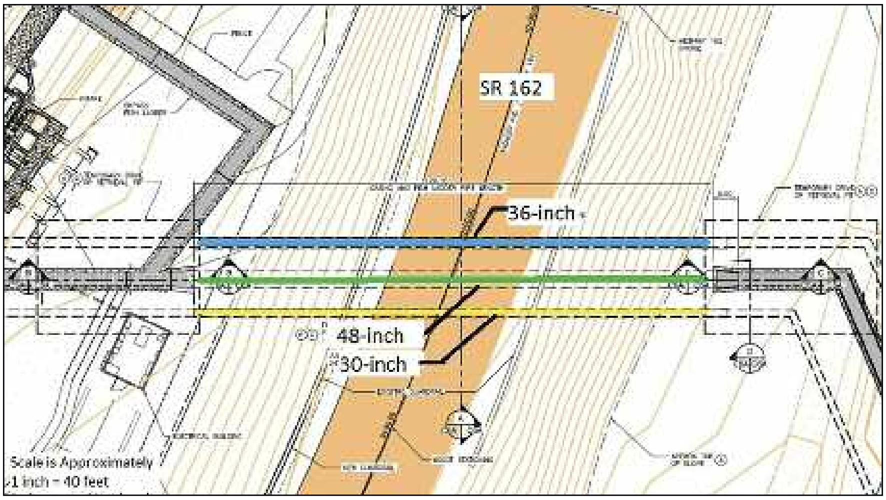



*Figure 2. Plan View (base map courtesy of MWH Americas)*

gravity juvenile release pipeline. The 36-inch-diameter pipe is below the groundwater level; however, the 48-inch- and the 30-inch-diameter pipelines could be above or below groundwater. The 36-inch-diameter pipe is a pressure pipe, and grade control was not as much of a concern. For the gravity pipelines, the elevation control point for the tie-in was on the north side of the crossing.

The design team included specific information in the drawings and specifications to mitigate risks associated with the soil and groundwater conditions and to emphasize the importance of grade control and careful construction practices:

1. The launch pit was on the north side where the grade control of the gravity lines was most important.
2, Baseline and daily settlement monitoring of the highway.
3. Language stating that grade is "critical to the hydraulic performance" of the system and requiring the contractor to pay for re-design of the piping system due to grade loss.
4. Soil and groundwater information provided to the contractor.

## CONSTRUCTION

Construction started with the contractor requesting to construct the launch pit on the south side of the embankment. After some discussions, the launch location for the pressure pipes was left open to the contractor's choice; however, the launch location for the gravity lines was as per the contract drawings.

The launch pit on the south side was excavated, and pipe ramming started by pushing the pipe casing into the ground using the jacking frame of an auger bore machine (Figure 3). The goal of this approach was to get sufficient casing/friction so the pipe would not "bounce" back when pipe ramming started. After the casing had been pushed about 4 feet in to the soil, the guide rails started to move. At this point the contractor decided to convert to pipe ramming for the next day. However, overnight the soil was able to slough into the open end of the casing and resulted in a sinkhole outside the launch pit.

Fortunately, settlement monitoring points had been placed and baselined and no settlement in the right of way was measured.

As the 36-inch pipe was being rammed, soil was "splashing" out between the collar and the hammer. Figure 4 shows the trail of saturated silty sand on the floor of the pit. During ramming, this soil was essentially liquefying and the plug that usually forms in a rammed pipe was not present. As the ram continued, the magnitude of "splashing" reduced as the distance increased. Pipe ramming continued successfully with a close eye on volume of material splashing out and the settlement monitoring points. After installation, the contractor surveyed the grade of the pipe. The north end was 12 inches lower than design; however, it was within the tolerances set in the specifications for the pressure pipe. Since the contractor had elected to install a larger-diameter casing, there was additional latitude and ultimately casing spacers where used to align the 30-inch-diameter HDPE pipe within the 36-inch steel casing and accommodate the grade loss.

Next was the 30-inch-diameter casing pipe. Better grade control was hoped for the 30-inch installation because the groundwater level was lower on the north side and the alignment was higher than the 36-inch installation. Unfortunately, the 30-inch casing lost about the same amount of grade as the 36-inch casing. The grade loss was still within the tolerances of the project specifications and some of the grade loss was able to be

*Figure 3. Auger Bore Jacking Frame Set-up*

*Figure 4. Wet soil is on the floor of the launch pit.*

recovered due to strategic use of casing spacers.

Maintaining grade within the specified tolerances was particularly critical for the 48-inch pipe because it was a gravity pipe and not an oversized casing. In anticipation of grade loss, the contractor set up the 48-inch pipe with a reverse grade. Additionally, the contractor set the pipe ram in an auger bore jacking frame to apply both static push and pneumatic hammering. An I-beam placed between the collar and the jacking frame transferred the static force to the pipe (Figure 5).

Within the first 13 feet of ramming/pushing, all reverse grade was lost and the pipe was flat. Extrapolating this grade loss to the end of the installation would result in a few feet lost. The contractor believed that the pipe was losing grade due to a combination of three things happening together:

- The pipe/soil combination was heavier than the original soil.
- The pipe ram was creating significant vibrations at the face of the pipe.
- The vibrations were "liquefying" the soil under the pipe which allowed the pipe to lose grade.

The contractor proposed switching to auger boring. He believed that the vibrations would go away, the weight of the soil in the pipe would be reduced and the soil would not liquefy. The design team was concerned that if auger boring were used there could be over-excavation at the face of the casing and may cause excessive settlement or sinkholes at the overlying roadway surface. After discussions with the contractor and WSDOT, the contractor was allowed to change methods, provided he held to the grade and settlement requirements in the specifications and he maintained the cutting head of the augers at least three feet inside the lead casing.

The soil coming out of the auger bore was silty sand with the consistency of low-slump concrete. The contractor was able to install the 48-inch casing the entire length. At breakthrough, the pipe had lost about eight inches of grade from the design grade. This was within the tolerances in the specifications.

**CONCLUSIONS**

In loose, saturated soils that can liquefy and flow under cyclic dynamic loading, soil plugs do not form. Design considerations

*Figure 5. Pipe Ram/Jacking Frame Combination*

*Figure 6. Auger Bore Set-up*

should be made to account for this possibility, and specifications should require the contractor to have a contingency plan. This contingency plan may be as simple as placing sand bags in the pipe prior to ramming.

The other lessons learned are to have flexibility during construction, to listen to the contractor, and to be prepared to make changes based on the actual conditions encountered in the field. A design is based on the information available at the time of design. With three pipelines being installed within essentially the same footprint, the best information we get is from the previous installations. The contractor anticipated possible challenges during construction due to the very soft soils and proactively set up the launch pit with the flexibility to switch between ramming and boring. It is helpful to discuss options and possible changes to construction based on soil information and soil behavior learned during construction.

### REFERENCES


- *GeoEngineers (2013) – Trenchless Design Report for the Voights Creek Hatchery Fish Ladder project, Orting, Washington*

- *Voight's Creek Hatchery, Site Plans by MWH Americas for WDFW, May 2013*

# The Pacific Northwest Region Uses Electro Scan Technology to Reduce RDI and Inspect Problem Pipes

**Jamie Johnson**
Product Specialist, Electro Scan Inc.
**Carissa Boudwin**
Marketing, Electro Scan Inc.

The Pacific Northwest has always had more rainfall than the national average – especially Oregon and Washington. As a result, rain-dependent infiltration (RDI) is an issue for many cities and municipalities. RDI can be difficult to locate using visual methods, such as CCTV, since in dry weather a defect may not be seen because it is not actively leaking. Meanwhile, in wet weather there may be too much water in the pipe to locate the defects visually. Electro Scan provides a much needed solution for these cities and municipalities since it recreates a wet weather event from the inside out.

Coos Bay, Oregon, is one such city that has turned to Electro Scan for a way to locate and quantify its RDI. The average rainfall

in Coos Bay is 55 percent higher than the average in Oregon and 66 percent higher than the average nationwide, which makes RDI a significant problem. With 93 miles of pipe, an aging sewer system, high groundwater, and poor soils, the City is looking for a way to better prioritize repairs and capital improvement projects.

While Coos Bay is mostly built out, there is a corridor within the city limits that has remained undeveloped. This area is zoned for industrial, commercial, single family, and multi-family development, all of which will add a large volume of sewage to the system.

The City has analyzed the existing sanitary sewer system that serves this area and has determined that this area is over capacity. The City does not have the funds to upsize all of the pipes from this area to the treatment plant in order to handle this new sewage, not to mention the significant amount of time that a project of this size would require and the disruptions to the public that it would cause.

As a more beneficial alternative, Coos Bay plans to use Electro Scan to locate where all their RDI is coming from. The idea being that by eliminating its RDI, the City will be able to make room in the pipe for the additional sewage.

However, prior to the City purchasing its own Electro Scan ES-620 for Sewer Mains system for this project, Electro Scan ventured to Coos Bay in December 2014 to perform a demonstration of the low-voltage conductivity testing technology.

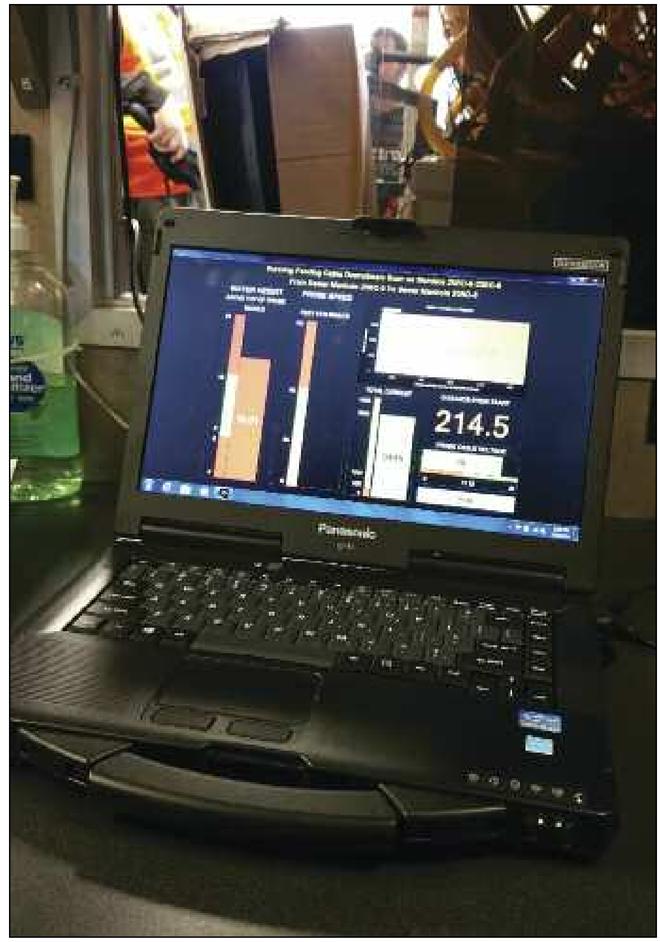
The Electro Scan probe releases a focused array of low-voltage, high-frequency electrical current of only 10 volts and 40 milliamps, which locates and quantifies all defects in non-conductive sewer mains and laterals.

Most sewer pipe materials are electrical insulators. A defect in the pipe that leaks water will also leak electrical current. For a constant applied voltage, the larger the defect, the greater the electric current. This is also the case for water in that for a given water pressure, the larger the hole, the greater the flow.

Since sewer pipe materials are generally asbestos concrete, brick, clay, cement, plastic, and reinforced concrete – i.e., all non-conductive materials that naturally prevent electricity from passing through or along the wall of a pipe – no electrical current should ever be able to “leak” or escape from inside a pipe unless, there is a crack or break in a pipe.

As the Electro Scan electrode, called a probe, passes through the pipe, it measures the variation of electric current flow through the wall of the pipe, then through the ground to an electrode on the surface – a metal stake driven into the ground.

Taking an electrical measurement every 14 milliseconds, the data is transmitted back up the CCTV truck’s cable and reel, and




then to the Electro Scan controller. There, the data is synched and delivered to the truck’s on-board PC which records all the data and operates the system via Electro Scan’s desktop application software.

Once a scan is complete, the software then sends the scan’s “raw data” to the web-based processing and viewing platform, where it is automatically post-processed, quantified, and displayed to anyone who has an account for that particular project or client. Additionally, an estimated gallons per minute (gpm) infiltration rate is assigned to each of the defects, and then the pipe as a whole (gpm rate is estimated to be +/- 40% and assumes one foot of head over the top of the pipe).

During Electro Scan’s December demonstration for Coos Bay, a total of four pipes were scanned – one PVC pipe and three concrete pipes. These four pipes had a combined length of 1,281 feet and ranged in size from eight- to 10-inch diameters. These four pipes were chosen due to the fact that they are not navigable by standard CCTV crawler cameras so no CCTV was available. However, Electro Scan was able to quickly and accurately navigate and assess the pipes.

Electro Scan’s results showed that the PVC pipe was in great shape and no defects were detected in its 445-foot length. However, the three concrete pipes were in varying conditions of disrepair. Over these three pipes, a total of 112 defects were located, representing an overall leakage rate of approximately 44 gpm, or 63,461 gallons per day (gpd).

In the worst of the three concrete pipes that were in poor condition, Electro Scan identified 66 locations of potential infiltration throughout its 419-foot length with an estimated infiltration rate of 25 gpm. While this pipe had defects spread throughout its entire length, it also had three spot repairs. Two of these repairs were successful at eliminating infiltration, but one of the spot repairs had a defect in the middle of the repair.

The second worst of the three concrete pipes was 270 feet long and had 37 defects with an estimated infiltration rate of 17 gpm, meaning it was in relatively bad shape as well. However, the third of the three concrete pipes was in decent shape with only nine defects throughout the 147-foot length of the pipe, with a total estimated infiltration rate of 2 gpm. It was found that three of the nine defects account for approximately half of the potential infiltration for that pipe.

The demo for Coos Bay and the quantity of potential infiltration on those particular concrete pipes served as an example of how Electro Scan is able to objectively locate and measure defects to help make better rehabilitation decisions. Quantitative data, like the data provided by Electro Scan, can be used to either determine the most efficient and cost-effective rehabilitation method or to determine which pipes warrant further investigation and inspection. By utilizing all technologies available, rehabilitation budgets can be maximized, and infiltration removed from the system most effectively.

In September of 2015, Coos Bay's staff presented Electro Scan's findings and project proposals to City Council members. The compelling data resulted in the decision being made for the City to consider the purchase an ES-620 for Sewer Mains system of their own. Electro Scan is thrilled to be working with the innovative team at Coos Bay. The City of Coos Bay will be the first adopter of Electro Scan technology in the state of Oregon.

Electro Scan looks forward to continuing its work in the region, helping cities and municipalities solve their infiltration problems by providing an innovative solution.

# Do We Microtunnel or Open-Shield Pipejack?

## The Martha Lake Gateway Sewer and Water Project Experience

**James Chae**
Jacobs Engineering Group
**Paul Richart**
Alderwood Water & Wastewater District

The I-5/164th Martha Lake Gateway Sewer and Water Improvement Project was completed successfully in November 2014, culminating in providing new sanitary sewer service for residents in the Martha Lake area of southwestern Snohomish County. The signature element of the project was a 540-foot, 66-inch-diameter trenchless crossing under 10 lanes of Interstate 5 near Exit 183. The evaluation of feasible trenchless methods and ultimate selection of open-shield pipejacking by the project team proved to be the right decision in overcoming the ground conditions encountered during the crossing and achieving completion with minimal delays or added costs.

### Project Overview

The Martha Lake Project consisted primarily of 4,200 linear feet of eight-inch to 14-inch gravity sewer main and 1,900 linear feet of 30-inch-diameter water transmission main in the vicinity of 164th Street SW and Interstate 5 near Exit 183 (about 18 miles north of Seattle). The new gravity sewer system provides residents in this area the opportunity to disconnect from their septic systems, and allows several businesses to abandon pumping systems. The new water transmission main is part of the District's ongoing efforts to upgrade its regional water system, replacing a structurally threatened section of a vital supply line with a safe new connection. As part of the overall improvements, a challenging trenchless crossing of I-5 was required in order to install a 12-inch gravity sewer (inside a 20-inch HDPE pipe) and 30-inch water main to their respective systems on the west and east sides of the Interstate (see Figure 1). The evaluation and selection of the right trenchless method would prove to be critical in addressing the Martha Lake Project's greatest risk.

Prior to obtaining geotechnical information for the I-5 crossing, an initial assessment of potential trenchless methods was conducted. Microtunneling and pipejacking were quickly considered to be feasible methods for their ability to handle the anticipated ground conditions and "drive" the full length of the 540-foot crossing. However, simpler and more cost-effective methods were also evaluated. Auger boring and pipe ramming were considered but ruled out due to the length of the I-5 crossing (i.e., inability to auger or ram 540 feet) and their lack of grade control as compared to pipejacking or microtunneling. Horizontal directional drilling (HDD) was also considered, but ruled out due to its inability to control line-and-grade to the required 1.00% slope of the gravity sewer. There were also concerns with hydrofracture of the drilling fluid from the minimal ground cover (13.2 feet) above I-5 near the southbound lanes.

### Geotechnical Investigation

Four soil borings and two test pits were completed along the I-5 trenchless alignment (Figure 2). A soil boring was located at both ends of the crossing, while additional soil borings were located in the median of I-5 and just east of the DOT right-of-way. Two test pits were completed at the east end of the crossing. These investigations indicated that the soils generally consisted of fill material over glacial till. The till layer started three feet to eight feet below grade, and consisted of very dense, gray, silty sand

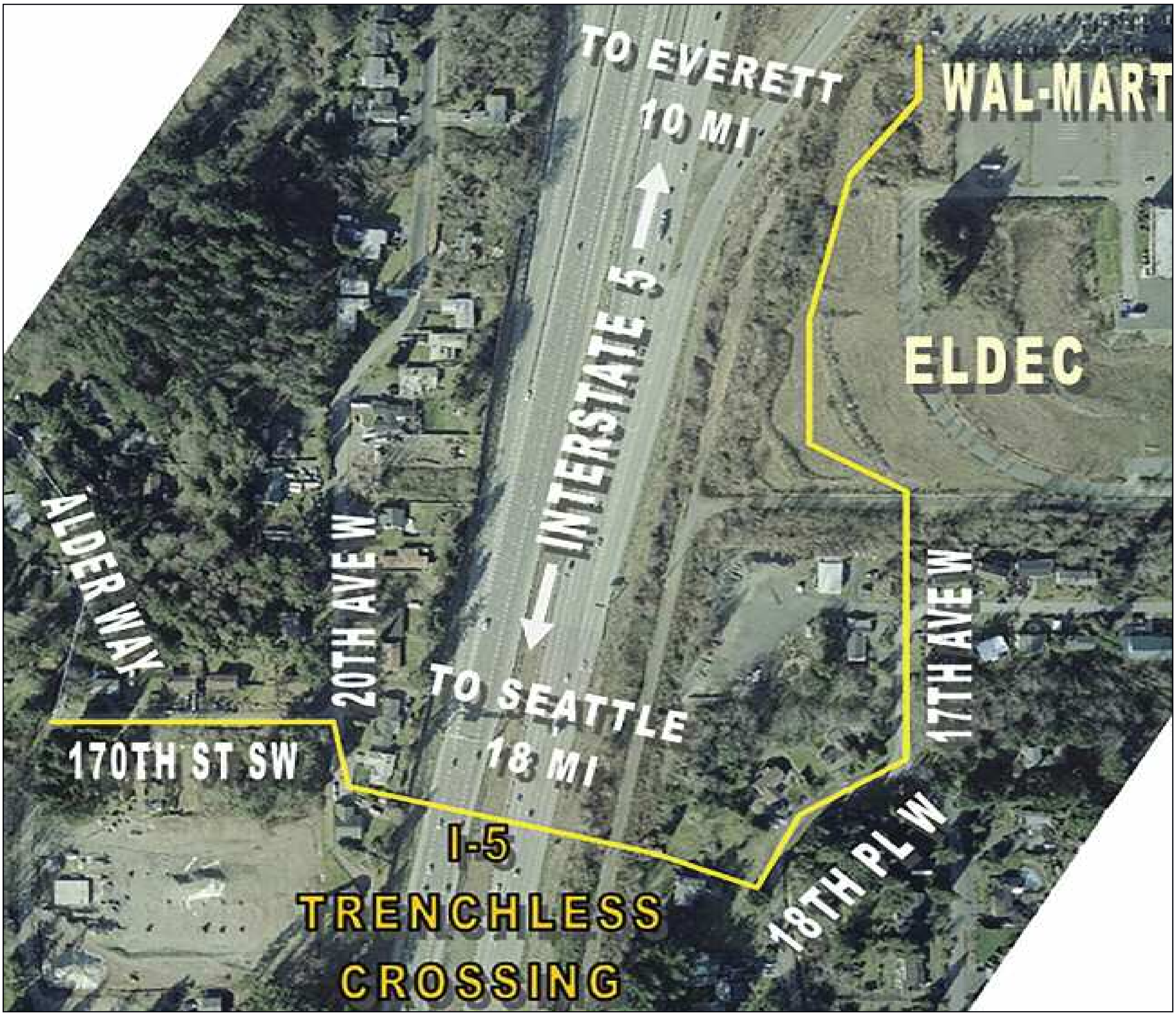



*Figure 1: I-5 Trenchless Crossing for Martha Lake Project*

to sandy silt with varying amounts of gravel. The upper two to five feet of the glacial till was considered "weathered till," which typically contains higher amounts of groundwater. Underneath the weathered till was very dense glacial till with 50+ blow counts.

Groundwater levels were also recorded using the monitoring wells installed during the soil borings. Groundwater was found to be within the weathered till for the soil borings near the eastern end of the crossing, approximately 11 feet above the proposed crown of the trenchless casing. However, due to the low permeability of the very dense glacial till underlying the weathered till, the team determined that the groundwater was perched above in the less dense weathered till. Furthermore, several borings and test pits encountered lenses of sand and gravel within the glacial till that could convey the perched groundwater above.

Additional geotechnical information was also obtained from an adjacent residential site development near the west end of the I-5 crossing. During excavation for the sanitary sewers for this development, eight boulders were encountered, ranging in size from two to seven feet in their maximum dimension. This led the project team to assume it would be very likely that boulders would be encountered in the glacial till along the trenchless I-5 crossing profile.

### Selection of Method

Following the initial trenchless methods assessment and evaluation of the geotechnical conditions, both microtunneling and pipejacking remained "on the table." At this juncture in the project, it was evident that the selected method would have to

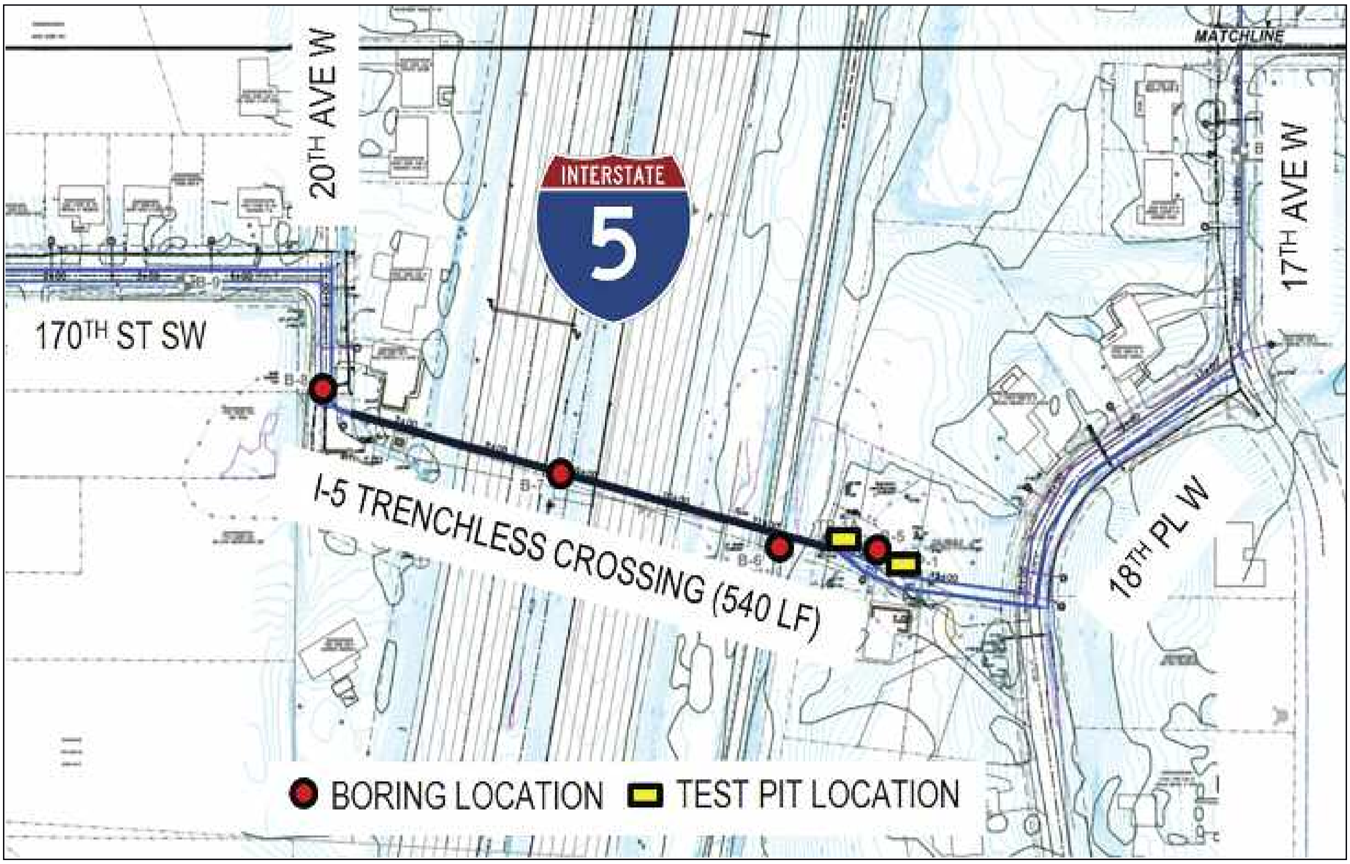



*Figure 2: Boring and Test Pit Locations for I-5 Crossing*

handle two primary risks: encountering boulders, and higher than anticipated amounts of groundwater. If microtunneling were selected, groundwater would not be a risk due to the pressurized, closed face of a microtunnel machine; however, if large boulders (especially like the ones discovered in the adjacent site) were encountered, there was a high risk that the microtunnel machine would get stuck under I-5. If pipejacking were selected, an open-shield machine would provide face access to manually break and remove boulders; however, if higher-than-anticipated volumes of groundwater were encountered, there would be a risk that the open-shield machine would not be able to stop the groundwater from flowing into the shield and hence potentially could cause settlement of I-5 above.

Through a process of additional evaluation of the geotechnical conditions and pros/cons of the remaining trenchless methods (see Figure 3), the project team ultimately decided that open-shield pipejacking provided the best chance for a successful crossing of I-5 due to its ability to provide face access for boulder removal if encountered. Although the geotechnical investigations indicated the presence of sand lenses that would introduce groundwater into the open-shield, the geotechnical team felt confident that the groundwater inflow would be minimal and temporary and posed less risk than encountering large boulders capable of stopping a microtunnel machine. Furthermore, a project constraint was written into the contract documents that required the I-5 crossing to be completed during the dry season between June 1 and October 15 when groundwater levels should be at their lowest point

## Results and Conclusions

Open-shield pipejacking of the I-5 crossing was successfully completed during the summer of 2014. As anticipated, groundwater inflow was relatively minimal; more importantly, four boulders were encountered that temporarily stopped forward progress of the pipejacking operations and required manual removal at the face of the machine before tunneling could commence again.

The successful completion of the I-5 trenchless crossing for the Martha Lake Project was the culmination of a collaborative design effort by the entire project team consisting of the prime consultant (Jacobs Engineering Group), geotechnical engineer (Shannon & Wilson), trenchless engineer (Staheli Trenchless), and owner (Alderwood Water & Wastewater District). Through the diligent efforts and expertise of all parties in analyzing the geotechnical conditions, the risks of the crossing, the feasible trenchless methods, and ways to mitigate the project risks, the selection of open-shield pipejacking was made. Continued diligent efforts by the expanded project team, including contractors Titan Earthworks and Northwest Boring, resulted in the successful crossing of 10 lanes of Interstate 5 and achievement of the project goal of providing sanitary sewer service and water transmission system improvements to the Martha Lake area residents and businesses.

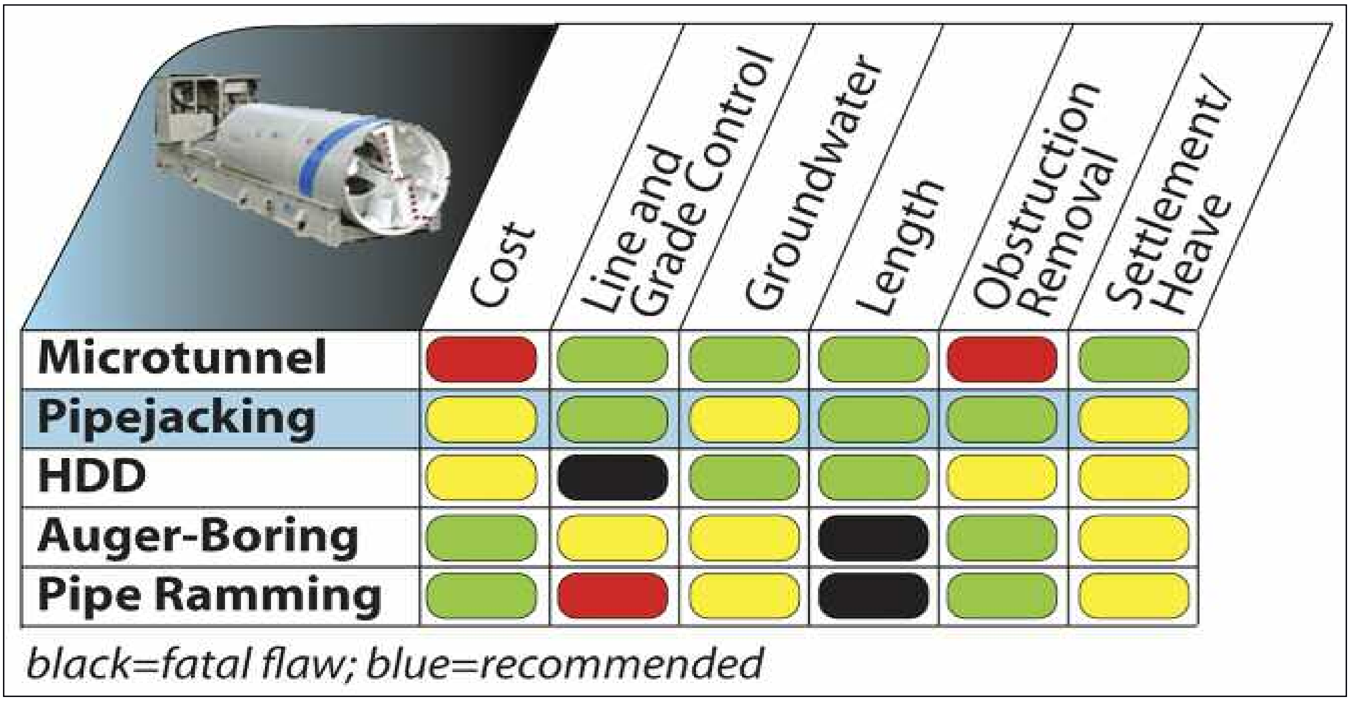



*Figure 3: Evaluation Matrix for I-5 Trenchless Crossing*

# Using Traditional Sliplining for Pipe Rehabilitation in Anchorage

**Matt Stephl**
Stephl Engineering LLC
**Brian Gastrock**
Stephl Engineering LLC

Sliplining, though an "older" method, continues to be a successful and cost-effective way of repairing pipes. This article will review examples of two recent projects that used sliplining to rehabilitate large-diameter pipe at challenging sites in Anchorage, Alaska.

**Postmark Outfall**

In 2014, traditional sliplining was used to repair a failing 60-inch-diameter outfall pipe that conveys storm water from Anchorage International Airport and discharges it into Cook Inlet. The 60-inch pipe conveys up to 15 cfs at peak times and conveys the surface runoff for a large portion of the airport. The 130-foot-long pipe was constructed in the 1980s with "nestable plates" that were bolted together as the culvert was assembled piece by piece inside a tunnel that was dug by hand in the stiff, fine-grained soils from the outlet discharge back towards the manhole.

There were several factors which proved challenging to the repair. The pipe was buried under 50 feet of soil cover, creating expensive and potentially dangerous dig conditions. Also, the upstream inlet had a single access point via a 60-foot-deep manhole. Finally, the outlet pipe was located on the muddy Cook Inlet tidal flats with no vehicle access.

*Collapsed outfall pipe and slope failure*

The failure was found in 2013 during a routine inspection by Alaska Department of Transportation crews. The crew found that the outlet end of the pipe was crushed and the 60-foot-tall bluff above the pipe had failed and sloughed away.

Upon discovery of the pipe failure, an

*Insertion of liner into host pipe*

inspection found that the crown of the 60-inch pipe had collapsed downward approximately 18 inches near the access manhole. Geotechnical soil probing determined that weak, fine-grained soils were used as backfill around the pipe at the manhole, as well as the cover material above the culvert. The use of this unsuitable fill material likely contributed to the pipe collapse.

Further investigations found that storm water was continuously leaking through the damaged 60-inch pipe at the failure point near the manhole connection, creating a conduit for water to travel along and outside the pipe and allowing continuous saturation of the surrounding soils. Over time, the flowing storm water leaking along the exterior of the pipe formed voids around the pipe and was assumed to be the factor that led to the slope failure and collapse of the CMP pipe at the outlet.

*Annular space grout strengthened the system and filled voids in the host pipe.*

Several rehabilitation techniques were evaluated to fix the vital stormwater discharge, including horizontal directional drilling (HDD), auger boring, open-channel flume, and open-cut replacement. To minimize costs and have more potential bidders, it was decided to pursue rehabilitation via traditional sliplining using a stiff 45-inch FRP (fiberglass reinforced pipe) Hobas liner pipe. The smaller pipe would still provide the required flow capacity and is strong enough to support the soils load from the deep bury depth. The biggest benefit of the sliplining solution was eliminating the massive and expensive excavation necessary for an open-cut pipe replacement repair project.

Work started in 2015 with the installation of a bypass system, excavation of the

*Tidal zone work area during low tide*

collapsed bluff, and construction of an access area at the pipe outlet. A hydraulic porta-power system was used to jack-up the 18-inch collapsed tunnel to allow room for the 45-inch liner to pass through. This culvert-reshaping work was accomplished by relieving the soil load above the collapsed tunnel area with augers, and compacted soil piers around the exterior of the collapsed pipe to improve the tunnel side-wall support. Strengthening the weak soils was also important for reducing future soil loads on the rehabilitated storm pipe.

Insertion of the 45-inch liner into the 60-inch host pipe was completed within just a few hours by the experienced South Central Construction, Inc. work crew. No high-resistance or pushing forces were encountered during the sliplining process.

To stiffen and strengthen the storm pipe and maintain sidewall support, the annular space between the new FRP liner and the old host pipe was filled with a flowable cement grout. Holes were drilled in the host pipe to allow the grout to fill voids in the soil around the host pipe exterior. Once grouted, surface restoration was completed and the storm pipe was back in service.

## Fish Creek Sewer Trunk Rehabilitation

In 2013, the Anchorage Water and Wastewater Utility (AWWU) performed closed circuit television (CCTV) inspections on a 48-inch reinforced concrete (RC) sewer pipe owned and maintained by AWWU. This sewer segment conveys up to 10 MGD, collecting wastewater from a large portion of Anchorage. The sewer pipe was installed in the 1960s and is located 25 feet deep in the mud flats of Cook Inlet – a tidally affected area that is submerged twice each day during high tide cycles.

The CCTV inspection found the crown of the RC pipe corroded and aggregate beginning to show in a pipe segment consisting of approximately 260 feet. Prior experience of working on the sewer mains and structures in this area supported the existence of corrosive H2S environment on the concrete structures. Due to the large flow volume and critical nature of the segment, the decision was made quickly to rehabilitate the 48-inch sewer pipe with segmented FRP, in live-flow conditions. Previous experience and depth of the existing sewer pipes made bypass pumping unrealistic with existing, locally available contractor equipment.

Several factors created challenging conditions for this sewer repair. The deep burial depths of the pipe and soil conditions required vibratory driven sheet piles in order to reduce excavation pit impacts. Because the site was located in the tidal area of Anchorage, it also had to account for potential adverse impacts to the endangered beluga whales in Cook Inlet. These potential impacts were identified in the permits which required crews to stop work if belugas were spotted or could be within 150 feet of the work area.

Previous experience on the site required that construction be completed in June and July to take advantage of longer summer days, dry weather, and fewer high tides. Coincidentally, the same contractor, South Central Construction, was the low-bidder and was able to complete the work within the limited construction window.

Work began in early June, installing the sheet piles and excavating the two access pits for sliplining. Once the pipe was cleaned, the concrete pipe was sliplined using 41-inch FRP in 20-foot lengths to rehabilitate the existing 48-inch pipe. Modeling completed by the utility confirmed that the slightly narrower pipe would still convey the 10-MGD flows. An AWWU lift station located 100 feet downstream of the segment was used to help control depth of flow by allowing below normal lift station operations while the new pipe was installed.

After the FRP was installed in each segment, the annular space was grouted with a low-density cellular concrete (less than 60 pcf). The lift station operations were changed in order to surcharge the liner, keeping it full of water while the annular

*Sliplining in live sanitary sewer flow*

space grout was pumped in. Once the grout was set, the sheet pile pits were backfilled with native material and the surface was regraded to original contours.

### Conclusions

Challenging project sites often require expanding one's toolbox to find efficient and cost-effective solutions for pipe rehabilitation. Often a variety of factors will drive the decision of which rehabilitation technique to use. For these projects, some of the relevant factors used to select sliplining as the rehabilitation technique were local contractor experience, available equipment, and available construction materials.

Although Anchorage has many qualified contractors, its location and environment prohibit the use of some techniques commonly used in other areas of the continental United States. The high cost of mobilization to Alaska can also limit trenchless options, requiring the engineer to select more common and tested construction techniques such as sliplining.

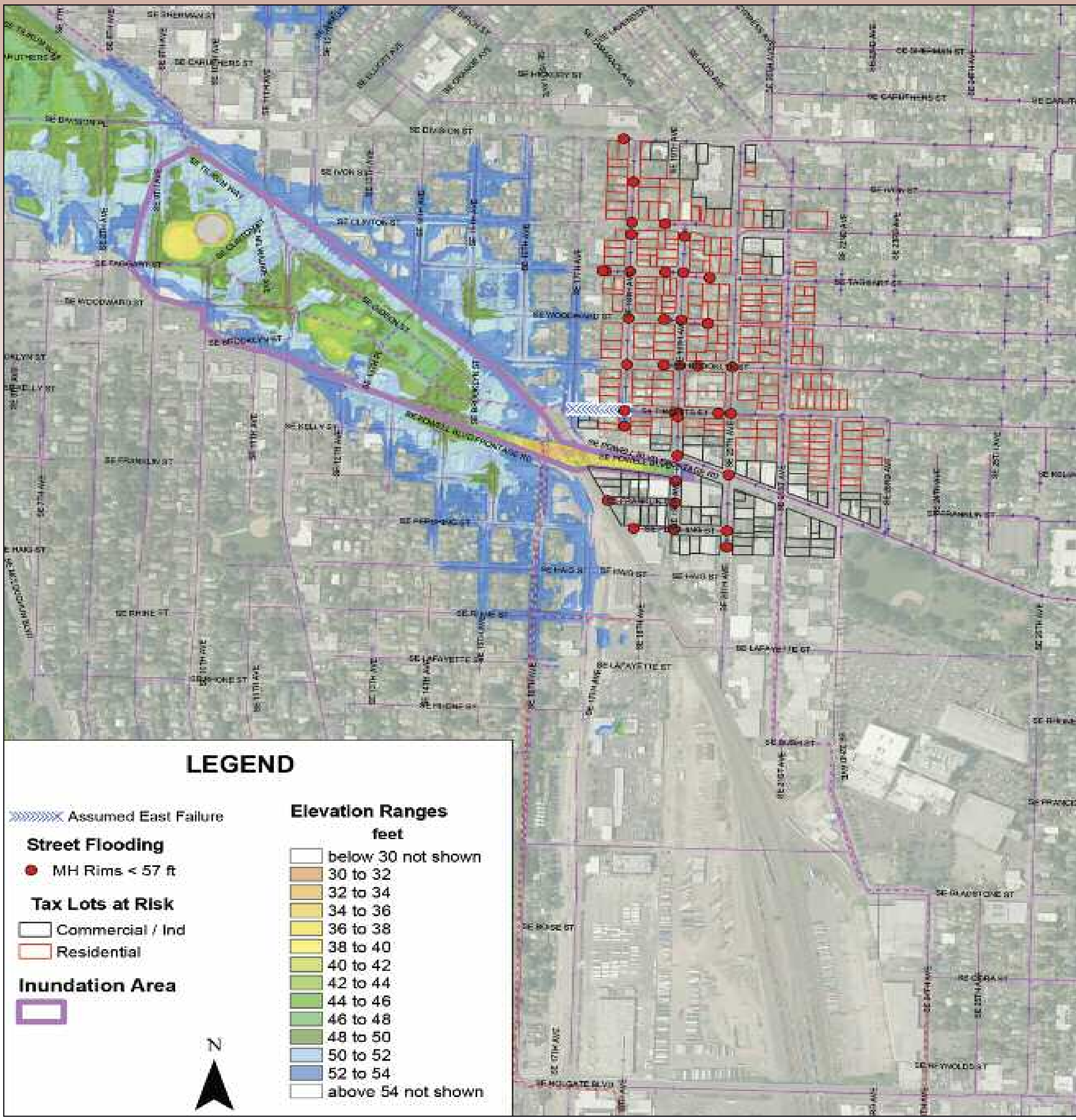
In these specific examples, project sites were located within sensitive tidal zones and subject to permit stipulations dictating time-of-construction restrictions and limitations. Using sliplining as a rehabilitation technique – especially in deep excavations – often lends itself for these types of construction sites, by reducing project footprint and providing a quick, efficient, and proven repair technique.

# Lifecycle Costs for Large-Diameter Rehabilitation – Portland's nBCR Method Applied to 100-Year-Old Brick Sewer

**Tammy Cleys**
*PortlandBES*
**Joe Hoffman**
*PortlandBES*
**Mark Johnson**
*CH2M*
**Dan Buonadonna**
*CH2M*

The Taggart Outfall 30 is one of the longest-serving large-diameter sewer pipes in the City of Portland. The 7,600-linear-foot, 66-to-120-inch brick sewer was constructed in 1906 to replace cesspools and reduce the death rate from typhoid fever and other infectious diseases in the densely settled neighborhoods (The Sunday Oregonian, Portland, March 25, 1906). At the time, it was the largest diameter and most expensive sewer Portland had constructed, with an initial budget of $250,000. Over the past century, the City's Bureau of Environmental Services has utilized this asset with multiple tie-ins, diversion structures, and retrofits that allow the tunnel to function today as a critical piece of the combined sewer infrastructure as collection and overflow. As part of their proactive approach to asset management, the City identified the Taggart Outfall as a candidate for rehabilitation to extend the life of the asset and maintain the system for the years to come.

The preliminary design process includes an alternatives analysis that calculated the full lifecycle costs for different trenchless technologies, including quantitative financial values for social, environmental, and economic costs. Site investigation work included geotechnical borings and pipe-penetrating radar which identified complex soil strata ranging from running sands to the compact alluvium of the region's Troutdale formation. The unique characteristics and large dimensions of the Outfall also allowed a broad range of trenchless technologies to be considered, including tunnel rehabilitation technologies. To address these challenges and find the "right size rehabilita-



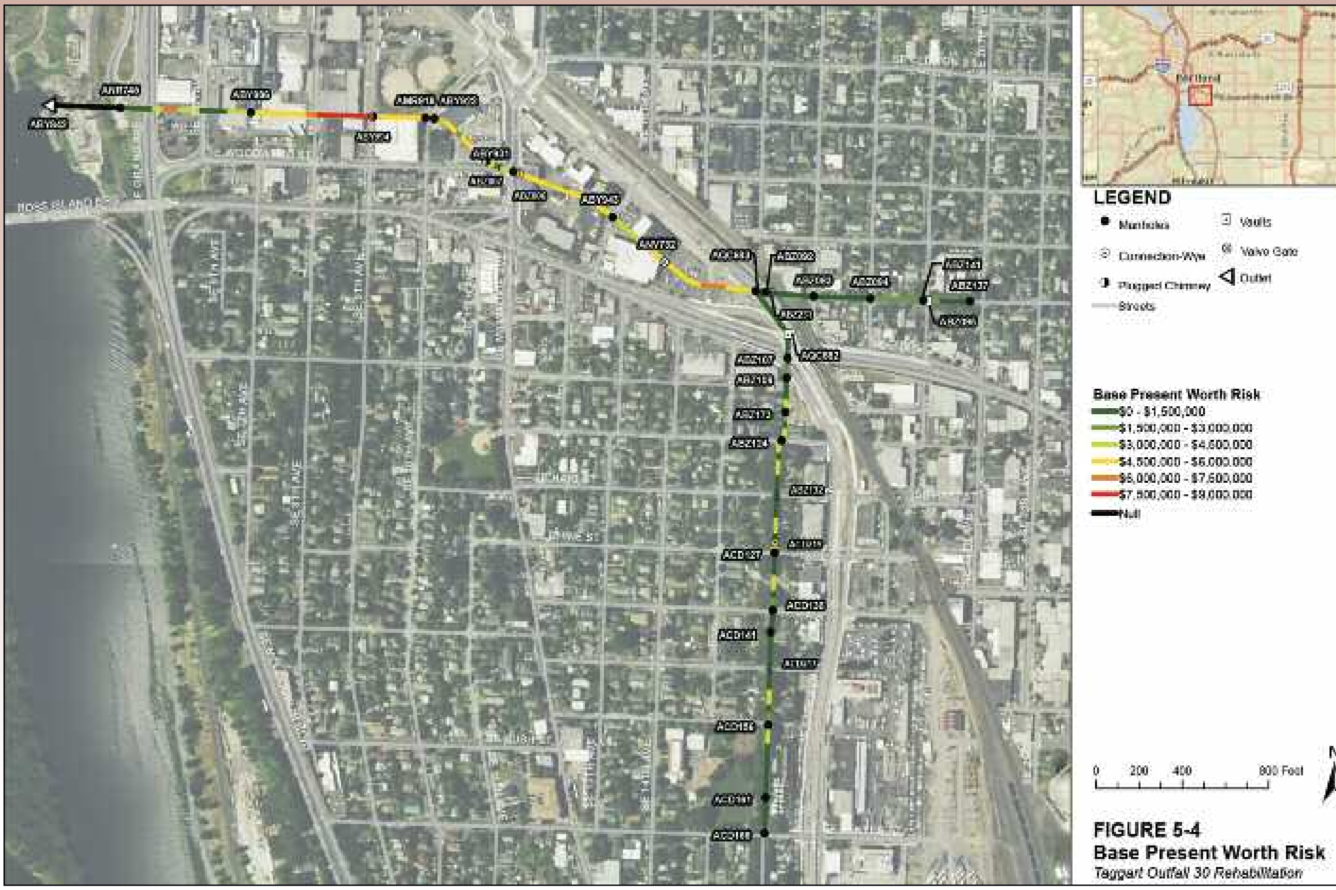

*Complex hydraulic models were used to simulate pipe failures at different locations and quantify the associated flood impacts.*

tion" plan, the City used a net benefit-cost ratio (nBCR) approach to evaluating the lifecycle costs and risk mitigated for each rehabilitation strategy. The result was a definitive lifecycle cost comparison that was used to select the large-diameter pipe and tunnel rehabilitation technologies for final design.

### Risk-Based Approach

The first step in the process involved establishing the right risk criteria for the project. The BES Asset Systems Management Group (ASM) uses a risk-based approach to manage the combined and sanitary collection systems. To assess the risk for each asset in the system, the primary inputs into the approach include consequence of failure (COF), likelihood of failure (LOF), cost of alternatives, and the resultant risk metric known as the nBCR.

The nBCR is a calculated value used to represent the comparison of benefits to costs. In this approach, the COF values are represented in dollars, and the LOF values are represented in time. The two values are combined to calculate base risk, which




*Base risk maps were used to identify the most critical locations and prioritize improvement alternatives.*

is the present-worth value for each asset that represents the current financial liability (in today's dollars) that the asset carries. Alternate risk can then be calculated as the present-worth value for the asset if changes (e.g., repair, rehabilitation, or replacement) are carried out. The nBCR value is then calculated using the following formula:

$$nBCR = \frac{(100\ year\ Present\ Worth\ Base\ Risk) - (100\ year\ Present\ Worth\ Alternate\ Risk)}{Project\ Cost}$$

Higher nBCR values correspond with higher returns on investment (in terms of risk dollars deferred) on repair, rehabilitation, or replacement projects. Using this method, a single common metric may be used to evaluate and compare the different rehabilitation alternatives.

The nBCR tool has been used successfully to select renewal projects for the City's small-diameter collection system, but was modified to apply to the large-diameter Taggart Outfall 30 system as follows.

- LOF values were changed to use a condition curve and remaining useful life (RUL) calculation that was specific to large-diameter brick sewer and reflected additional condition assessment data in the form of a pipe-penetrating radar (PPR) survey to detect voids in and behind the pipe wall. Geotechnical investigations and analysis were also used to characterize the likelihood of failure due to a seismic event, which was of minor impact due to the dense alluvium and Troutdale soil formations.
- COF values were modified to account for the larger and deeper excavations associated with large-diameter point repairs, and also to account for the cumulative upstream basement and surface flooding impacts. With technical assistance from David Collins Engineering, the BES ASM developed complex flooding scenarios for a one-year storm to quantify the number of homes, businesses, transit routes, and population inconvenience hours potentially impacted, and estimate the costs associated with these impacts.

After the modifications to LOF and COF were implemented into the risk calculation method, new present worth base risk values were calculated for Taggart Outfall 30. These values were calculated as a total anticipated life-cycle expenditure per 50-foot pipe segment failure and mapped for the outfall. The results of the risk analysis were used to identify the locations along the alignment where the City carried the most risk, in terms of the highest base present worth values in a "run to failure and repair" scenario. In general, pipes with higher positive risk values are stronger candidates for rehabilitation to mitigate the City's risk exposure.

### Rehabilitation Technology Alternatives

Having accounted for the base risk term in the nBCR metric, the next step required the development of potential rehabilitation alternatives and their different risk impacts. Multiple trenchless technologies were reviewed for their applicability to rehabilitation of the outfall. This process was facilitated by a two-day workshop in which vendors from different rehabilitation technologies gave presentations to the project team and discussed the capabilities and limitations of the products and methods.

Earlier condition assessment identified several types of defects (deformation, voids, cracks/fractures, missing mortar, and missing bricks) of varying extent throughout the pipeline. In addition, flow monitoring and hydraulic modeling had revealed that the Outfall was subject to regular surcharge and pressurization. Seismic resiliency was also an important consideration for potential alternatives.

Based on these criteria, a rehabilitation requirement category was prescribed for each pipe section. Using the rehabilitation requirement categories, the rehabilitation technologies were classified by their ability to meet those requirements. A pre-screening process to preclude technologies that were incompatible with the project requirements was also performed during this stage.

One of the objectives of the alternatives development process was to evaluate the benefits of rehabilitating pipe segments that were not necessarily in critical condition or high risk, but were immediately adjacent to other pipe segments at high risk and their rehabilitation may realize a positive nBCR. With this information, multiple combinations of rehabilitation technologies and quantities of pipe receiving rehabilitation were developed into distinct project alternatives.

The alternative risk for each of these alternatives could then be calculated based on to what extent they each decreased the likelihood of failure (by remediating defects) and extended the remaining useful life of the Outfall (depending on the design service life of the technology).

### Lifecycle Cost Comparison

The final element of the nBCR calculation requires the cost estimate for each of the potential alternatives. The cost estimates used needed to include direct costs, indirect costs, environmental, and social costs (e.g., traffic disruption) in order to fully represent the merits of each alternative. Direct costs include rehabilitation materials and installation, bypass pumping, cleaning, post-installation inspection, access shaft construction, traffic control during construction, general conditions costs, waste, and contingencies. Indirect costs include construction management, site inspection, testing, design, easement, environmental compliance, public involvement, startup, and closeout costs. The accompanying table shows the final results after the base risk, alternate risk, and project cost were input into the formula to calculate nBCR for each potential technology alternative.

**nBCR Calculation Results**

| Technology | Overall nBCR |
|---|---|
| Sliplining | 6.9 |
| Spray applied | 12.9 |
| CIPP | 3.9 |
| Tunnel liner plate | 14.0 |
| Slipform | 12.2 |

The results of technology screening indicated that spray-applied liners and tunnel liner plate had among the highest nBCR values for the Taggart Outfall 30 project. The particular circumstances that surrounded the project and influenced the nBCR calculation results included the following.

- The dense urban location and 60-ft depth of the sewer significantly increased the costs and risks associated with technologies that required access shafts.
- The recurrence and magnitude of surcharge events up to 14 feet required technologies that could be designed for pressurized conditions.
- Addressing the active flows in the sewer increased the time and construction costs for technologies that would require bypass pumping of the sewer.
- The relatively short summer construction window favored technologies with rapid installation times over those that may require multiple construction seasons.

The results of the nBCR analysis were used to refine the final alternatives and move into the pre-design stage.

### Benefits and Next Steps

For the Taggart Outfall 30 Structural Rehabilitation Project, the outcomes of the nBCR calculation and evaluation method were sufficient to make an informed and valid alternative selection. By quantifying the consequences of failure (in dollars), and reducing all the potential alternatives down to triple bottom line costs (in dollars), much of the subjectivity of other alternative analysis methods is avoided.

While the Taggart Outfall 30 project team moves forward into design, the Portland Bureau of Environmental Services is continuing to refine and improve their powerful nBCR asset management tool.

# Assessment of Ground Vibrations Associated with the Pipe Ramming Method

**Armin W. Stuedlein, PhD, P.E.**
*Associate Professor, Oregon State University*

Owners, their consultants, and contractors have increasingly elected to use pipe ramming as a trenchless alternative for the installation of culverts and pipelines under road and rail embankments and other civil infrastructure. The pipe ramming method allows the support of the soil being penetrated and, with properly designed cutting shoes, results in little surface expression of ground deformation (i.e., settlement). The ground deformation performance makes pipe ramming an ideal trenchless alternative for culvert crossings under embankments with active traffic, preventing costly road and rail closures that can considerably impact its users.

The pipe ramming method consists of driving a pipe or casing using percussive blows generated by a pneumatically- or hydraulically-powered encased piston rammer (i.e., hammer). The impact delivered to the pipe by the hammer during ramming results in what engineers term a "stress wave", which travels down the casing at the compression wave speed of the casing material (typically steel, characterized with a p-wave velocity of about 16,500 feet per second). Although some of the stress wave, or energy, is reflected at the face of the casing and travels back up the casing to result in what some practitioners call "rebound", or the momentary backward motion of the casing, the remaining portion of energy is transferred to the surrounding soil to produce permanent forward displacement of the pipe and ground vibrations. These ground vibrations can annoy nearby homeowners, or potentially result in damage to structures that can include cosmetic cracking of architectural cladding to more critical manifestations such as structural fractures in walls and floors of buildings. Therefore, the installation of culverts and casings with pipe ramming in dense urban environments requires the assessment of the potential for damage due to ground vibrations. However, there has been very little data reported on the magnitude of ground vibrations possible or the degree to which vibrations attenuate which can guide practitioners who are tasked with assessing and mitigating potential damage.

Recent research carried out at Oregon State University and funded by the Oregon Department of Transportation and members of the Northwest National Utility Contractors Association has shed new light on the generation and attenuation of ground vibrations associated with pipe ramming installations. This article summarizes some of the key findings of this research.

## FULL-SCALE FIELD TEST OF PIPE RAMMING

Although there are few soils ill-suited for the application of pipe ramming, the method is particularly advantageous in soils with a high fraction of gravels, cobbles, and boulders, conditions that are relatively difficult for some other trenchless methods. Therefore it was desired to identify a field test site that was characterized with these kinds of soils. Lyle Schellenberg, then president of the Northwest Utility Contractors Association, knew of just such a site: the yard of Emery and Sons, Inc., just outside Salem, Oregon. Bill Martinak of Emery and Sons concurred, and graciously allowed us to use the site to conduct a full-scale field test on an instrumented, 1,070 mm (42-inch) diameter, 35 m (116 ft) long pipe, donated by Jim Gonzales of Gonzales Boring and Tunneling. Many others also contributed to the field test, including Armadillo Underground, JW Fowler Construction, Moore Excavation, Peterson Machinery Co., RDO


*Figure 1. 400 mm HammerHead used during measurement of ground vibrations*

Equipment, and Wyo-Ben, Inc.

Hollow-stem auger borings indicated, and confirmed during excavation of the launch pit, that the stratigraphy consisted of 1.7 m of medium dense to dense, silty, sandy gravel overlying dense to very dense, silty, sandy gravels with abundant cobbles – a perfect soil unit for the evaluation of pipe ramming. Prior to initiation of the test ram, the hammer-pipe system was assembled on steel tracks placed to help align the pipe, set at a horizontal grade, and support an auger boring machine used to excavate spoils. The centerline of the pipe as constructed in the launch pit was approximately 2.2 m (7.2 ft) below the adjacent ground surface.

The first five segments of approximately 6 m (20 ft) long pipe were driven using a 400 mm pneumatic HammerHead (Figure 1), characterized with an estimated rated energy of 6.4 kN-m (4.7 kip-ft) and blow rate of 231 bpm. The last segment of pipe was installed using a 610 mm Grundoram Taurus with rated energy of approximately 18.6 kN-m (13.7 kip-ft) and 180 bpm. In one of our principal findings, we observed that the actual energy transferred to the rear of the pipe could be considerably smaller than that rated for each hammer depending on the type and condition of the hammer-pipe connection (see Meskele and Stuedlein [2013] and Meskele and Stuedlein [2015b] for additional details). While this is not desirable from the standpoint of production installation rate, smaller transferred energy necessarily leads to smaller pipe ramming-induced ground vibrations.

## MEASUREMENT AND INTERPRETATION

Among the other performance metrics of interest during this research field test such as the static soil resistance to ramming, drivability, and driving stresses (see Meskele and Stuedlein [2015a], [2015b]), we wanted to understand the differences in magnitude and rate of attenuation of ground vibrations. Ground vibrations were measured using a Minimate Plus seismograph typical of that implemented to monitor construction vibrations. Measurements were made along three sections transverse to the pipe alignment, and each section used four measurement locations relative to the centerline: one directly on the centerline, and the remaining at offsets of one diameter, D (1.1 m), 3D (3.2 m), and 5D (5.3 m). This allowed the observation of vibrations from an advancing pipe that are associated with forward propagation and lateral propagation. Forward propagation refers to those vibrations that are generated from the leading edge, or face, of the pipe, whereas lateral propagation refers to those vibrations that emanate largely from the shearing of soil along the length of the casing. Those measurements made ahead of the leading edge of the pipe reflect compressive p-waves; once the leading edge of the pipe passed a given monitoring section, the measurements correspond to polarized shear or s-waves. Thus, all of the vibration monitoring points were essential for decoding the ground response. Owing to the manifest role of the hammer energy in the production of the ground vibrations, it was also critical to measure the actual energy being transferred to the pipe from the pipe rammer. Hammer generated stress waves were measured for each impact using the Pile Driving Analyzer, a tool commonly used to conduct dynamic loading tests of driven piling, and this data was used to calculate the actual energy transferred for each blow. The estimation of the magnitude of the actual energy transferred is the key to conducting appropriate drivability and ground vibration attenuation analyses of driven pipes.

Although several models for the prediction of ground vibrations associated with various construction activities have been proposed, an empirical power law suggested by Wiss (1981) was adopted herein to represent the magnitude and attenuation of pipe ramming-induced vibration. The model relates the magnitude of ground vibration to the hammer energy, and radial distance between the source of the energy and a location of interest (e.g., geophone sensor location). The power law, shown below, makes use of what is termed the scaled distance, defined as the radial distance normalized by the square root of energy to estimate the peak vector sum (PVS) velocity, v, which is defined as the root sum of squared orthogonal velocity components (i.e., vertical, longitudinal, and transverse):

$$v = K_d \left[ \frac{r}{\sqrt{E}} \right]^{-n}$$

In this equation, $K_d$ = intercept value of vibration amplitude at "scaled distance" $r/\sqrt{E} = 1$, E = energy of the hammer transferred to the pipe, r = radial (or hypocentral) distance between the source of energy and location of interest, and n = the rate of attenuation.

## KEY FINDINGS

The key to understanding any ground motion problem of interest is to characterize the magnitude, duration, and frequency content of the vibration. In pipe ramming, the duration of vibration is rather predictable; turn on the hammer, experience ground vibrations; cut the air supply (or hydraulic), and so terminate the vibrations. Our field observations, however, showed that the pipe ramming-induced vibrations consisted of a wide range of amplitudes and frequencies, which ranged from 1 to 100 mm/sec and 20 to 100 Hz for the conditions analyzed. Figure 2 presents a sample of our findings reported in a forthcoming journal article (Meskele and Stuedlein 2015c): Figure 2a shows the relationship between the magnitude of PVS ground velocity and scaled distance for forward-propagating ground vibrations, whereas Figure 2b shows the same information for laterally propagating ground vibrations. Forward-propagating ground vibrations produce greater magnitudes of PVS velocity at low scaled distances, but these attenuate quickly with increases in the scaled distance. On the other hand, we observed that the PVS velocity for laterally propagating velocities were much lower than those of forward-propagating velocities at small scaled distances, but the rate of attenuation was also lower, meaning that the magnitude of vibration did not decrease with distance as rapidly with scaled distance. Practically speaking, this means that ground vibrations may not cease to represent a concern following the advance of the leading edge of the pipe beyond a particular point or structure of interest.

Power law attenuation model parameters (i.e., Kd and n) were back-fitted using least squares regression to provide pipe ramming-specific guidance for the estimation of vibrations in the difficult soils penetrated at the test site. Figure 2 presents the best fit (solid lines) and upper bound (dashed lines) attenuation models, and the interested reader may reproduce these models for any distance and energy magnitude using the power law model parameters summarized in Table 1.

Anticipation of a potential issue through appropriate planning is critical to any engineering undertaking, particularly when experience with an emerging technology is not as deep as with more established technologies. Thus, it is often helpful to interpret new findings through comparison of similar phenomena for which greater experience may be available. We found it helpful to compare our observations to those summarized by Charles Dowding, an established expert on ground vibrations produced by construction activities, as shown in Figure 3. The comparison readily makes the case that pipe ramming is capable of producing similar magnitudes of vibration as many other types of common construction activities, and that it would make good sense to consider the potential impact of pipe ramming-induced ground vibrations on any existing structure or buried utility. We hope that this first study will not be the last to report critical field performance data, and encourage owners' representatives to observe, document, and report their experiences to the industry, as such information can only result in the increasing use of an often advantageous trenchless pipe and culvert installation method.

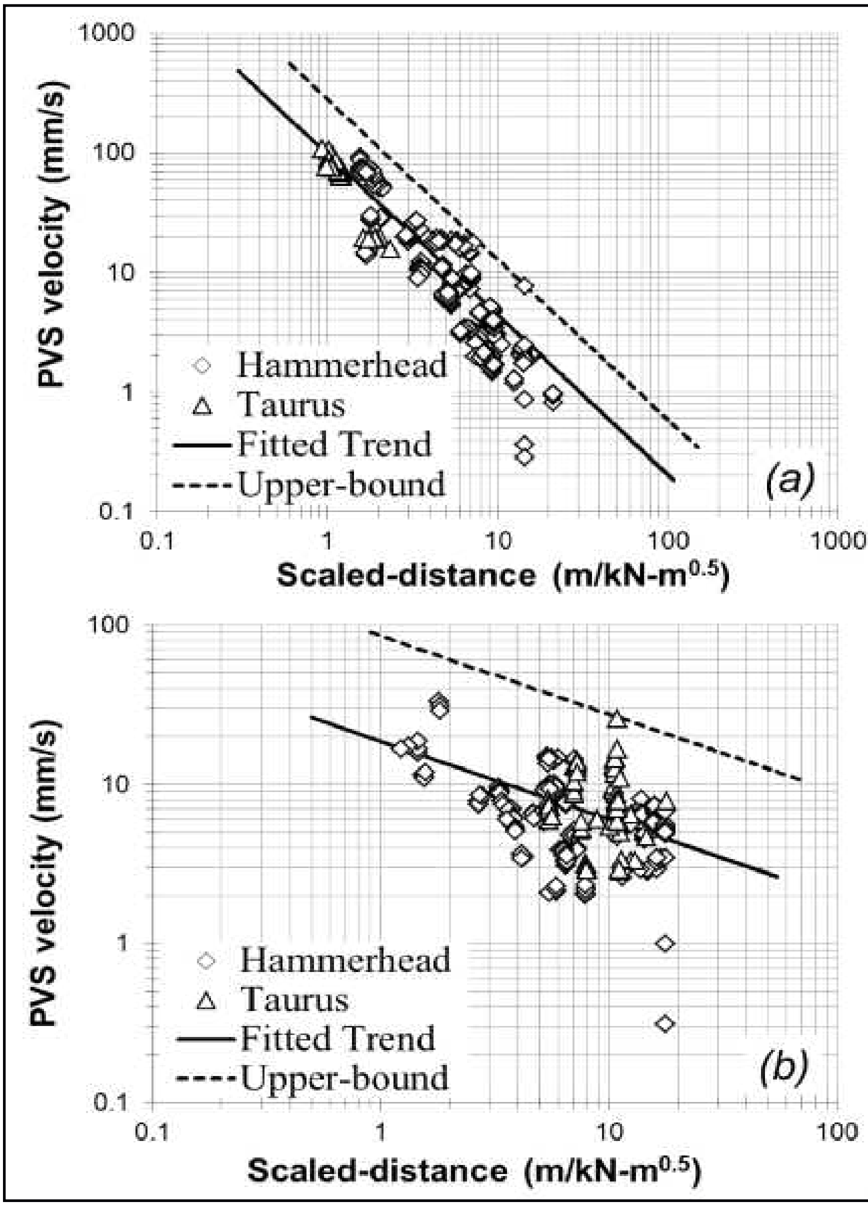



*Figure 2. Ground vibration measurements and calibrated attenuation models for (a) forward propagation and source of energy at the rear end the pipe and (b) lateral propagation and source of energy at the rear end the pipe (modified from Meskele and Stuedlein 2015c)*

| Model parameter and bias statistics | Forward propagation from the rear end | | Lateral propagation | |
|---|---|---|---|---|
| | Best fit | Upper bound | Best fit | Upper bound |
| $K_d$ | 97 | 280 | 19 | 85 |
| $n$ | 1.34 | 1.34 | 0.50 | 0.50 |

*Table 1. Attenuation model parameters (modified from Meskele and Stuedlein 2015c)*

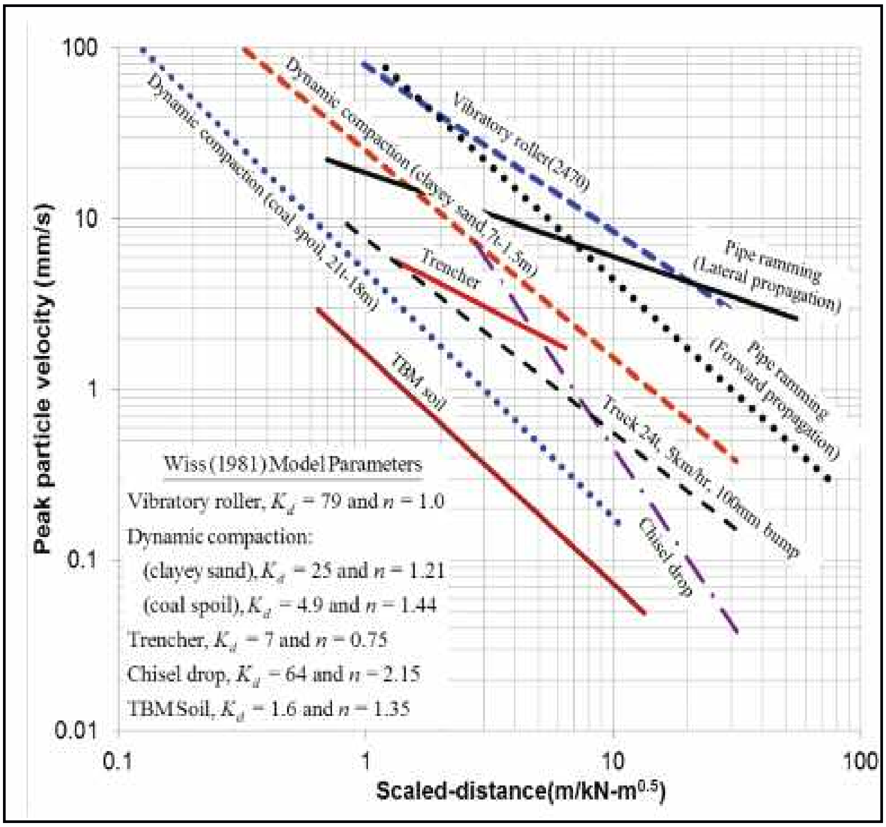



*Figure 3. Variation of peak particle velocity with scaled-distance for various types of construction equipment (modified from Dowding 2000 and Meskele and Studlein 2015c)*

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# Sanitary Sewer Interceptor Rehabilitation Using a New Cure

**Jessica Rinner, P.E.**
Clean Water Services Engineer

**Joe Amerson**
Clean Water Services Construction Inspector

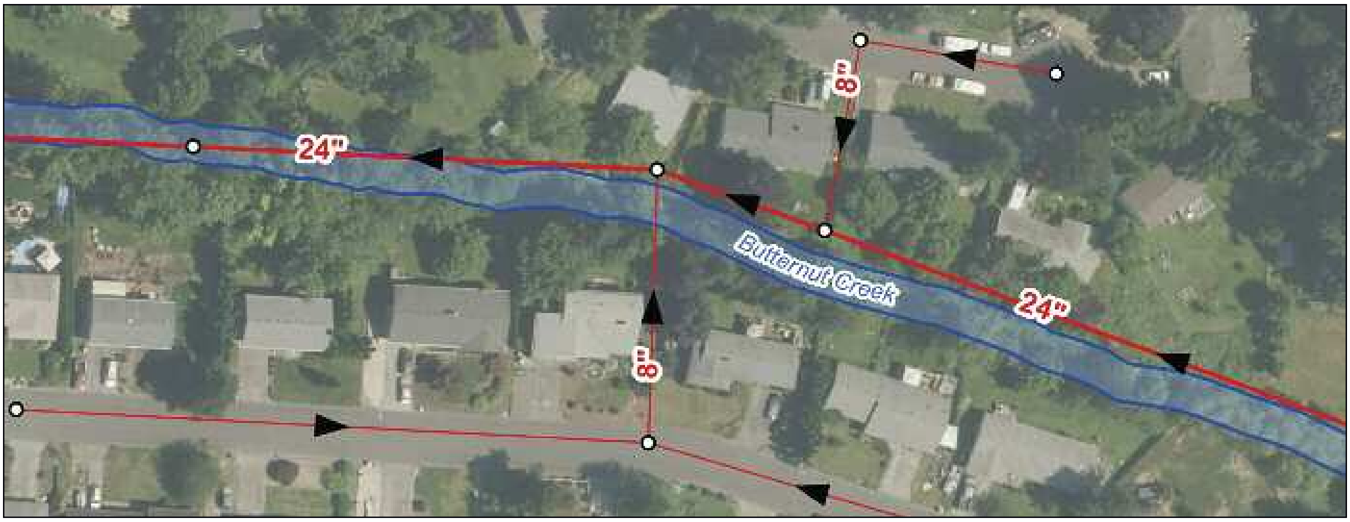


*Figure A: Interceptor in relationship to creek*

Clean Water Services (District) is a water resources management utility committed to protecting water resources in the 700-square-mile Tualatin River Watershed in Oregon. Within the service area, District maintains approximately 800 miles of sanitary sewers ranging in size from six inches to 84 inches in diameter, 41 pump stations and four treatment facilities. Of the 800 miles of sanitary sewer, more than 100 miles are interceptors that have a diameter of 18 inches or larger. As is the nature of a gravity sewer system, interceptors are located in low areas. The majority of interceptors are located within creek corridors.

Two separate types of routine inspections are conducted on sanitary sewer interceptors. Annually, District employees conduct a visual inspection by walking the path of the interceptors and opening manholes to look inside. Additionally, there are routinely scheduled closed circuit television (CCTV) inspections. District's operating standard is to CCTV every sanitary sewer pipe once every eight years. The combined data collected by these inspections is used to identify any defects that may compromise an interceptor's future structural and operational integrity. Due to these inspections, District had identified the Butternut Trunk Interceptor as a large contributor of inflow and infiltration (I/I) into the sewer system.

The Butternut Trunk Interceptor is approximately two miles long and constructed of concrete sewer pipe ranging in diameter from 21 to 24 inches. The pipe is relatively new; it was installed in 2008 to replace a 15-inch interceptor. The full length of this interceptor is located within the Butternut Creek corridor. Figure A illustrates the location of the interceptor within the creek corridor. To further complicate access issues, the surrounding neighborhood development had limited the access. This particular

*Figure B: Factors limiting access to interceptor*

*Figure C: UV-curing point repair insertion*

interceptor and creek are located behind property with many backyards having fences, mature landscaping, and overgrown vegetation. Figure B illustrates some of these factors limiting access to the interceptor.

The Butternut Trunk Interceptor and some of the surrounding collection system were selected as part of District's Large Diameter Sewer Repair Project for rehabilitation. The project included cleaning and CCTV inspection, and then pressure testing and grouting of leaking joints in approximately 13,000 feet of sewer pipes ranging from eight to 24 inches. Previously, many rehabilitation projects had been done using chemical grouting, which has been used for over 50 years as a method to stabilize soils and stop groundwater leakage without costly and intrusive excavation. The initial design of the project was to rehabilitate the sewers using grouting. It was estimated that 50 percent of the pipe joints within the Butternut Trunk Interceptor were failing and would need to be grouted. In addition, 18 manholes would be rehabilitated using injection grout to stop active leaks so that an epoxy coating could be applied to the joints and pipe penetrations, and 25 manhole frames and covers would be replaced with a composite gasketed version. The winning bid for this project came in at just under $1.1 million.

Pressure testing began after the cleaning and CCTV inspection portion of the project was completed. It was determined that instead of the estimated 50 percent, in fact less than 10 percent of the joints were failing. Additionally, the joints that were failing were within two to three pipe segments upstream or downstream of a manhole. This would indicate that sheer joints were not used in the original construction of the interceptor. Upon review of the CCTV inspection of the freshly cleaned pipe there was limited evidence of I/I at the joints, which corroborated the reduced percentage of joint failure.

Due to this new information, the scope of the project changed. District decided to utilize a structural repair method instead of the original proposed pressure testing and grouting method of rehabilitation. District decided to utilize UV-cured short liners as the method to repair the failing joints. In addition to stopping the I/I, the liners would provide a structural repair which would bridge the failing joints.

The UV-cured short liners are installed like other lining sys-

*Figure D: Manhole condition prior to rehab*

*Figure E: Manhole after rehabilitation*

tems using a bladder to expand and press the liner to the inside of the host pipe. The cure time in this lining process is short (10 minutes), allowing for quick installation. One obstacle with the short cure time and the product curing when exposed to UV light is that the liners cannot be exposed to sunlight. Crews worked quickly under tents and then wrapped the liner in black plastic to be carried to the manhole for insertion into the pipe. Figure C shows black plastic wrapped around a liner secured around the bladder with the UV light system inside being lowered into the manhole for installation.

The liners were installed at locations where infiltration had been identified during the CCTV inspection. Manholes were rehabbed using injection grout to stop active leaks and then epoxy coating of seams and pipe penetrations. Figure D is an example of a manhole condition prior to rehabilitation. This manhole had the active leaks stopped by injection grouting. Then the seams and pipe penetrations were epoxy coated. Figure E is an example of the internal finished product.

In addition, the manholes in this project that could be inundated when the creek runs at high levels had the old castings removed and composite frames and covers installed. District installed composite frames and covers that had gaskets and locking features. Figure F depicts a newly installed composite frame and cover with the old casting set to the side. District field personnel have found the lighter weight of the composite frames and covers to be a great benefit when working in hard-to-access, slippery conditions.

Upon completion of the project, 41 UV-cured short liners were installed within the interceptor. For the manholes, 21 required injection grouting and 27 had the epoxy coating applied. Lastly, 45 new composite manhole frames and covers were installed. The final project cost was approximately $825,000, which was $275K less than the original bid. Because this project was conducted on an interceptor with a large tributary area, it is difficult to isolate the interceptors' flows to estimate I/I reduction for this particular project. We do, however, know that upon visual inspection there appears to be no active I/I and the pump station downstream has had its pump run times reduced due to upstream rehabilitation.

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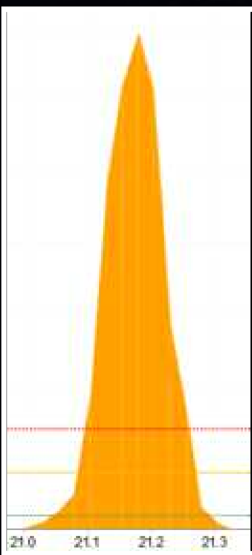


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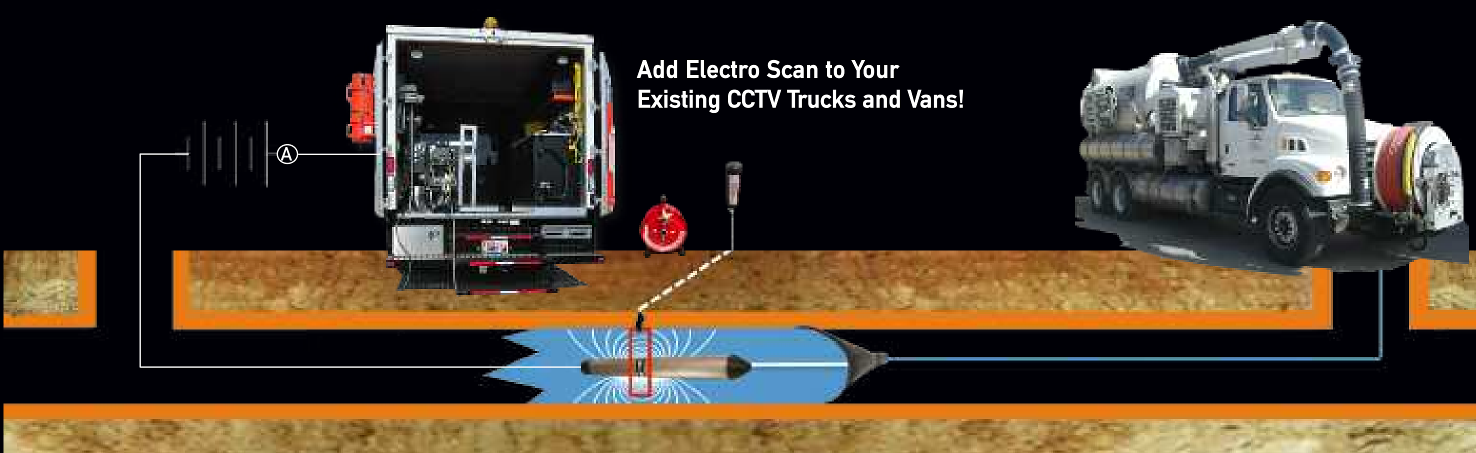


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