NASTT PACIFIC NORTHWEST CHAPTER

Pacific Northwest Trenchless Review

2020

Forward with Trenchless Technology

Pacific Northwest Trenchless Review

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Also...

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Unit 1 – 73 Fontaine Crescent
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President
Elaine Chouinard
204.255.6524
elaine@ptrcommunications.com

Editor
Mike Stimpson
807.346.0510
mike@ptrcommunications.com

Advertising Sales
Darlene Madill
218.324.2801
darlene@ptrcommunications.com

Mari Ann Ruczak
204.257.2133
mariann@ptrcommunications.com

Layout & Design
Jim Schmidt
Lunch Pail Productions

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

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Forward with Purpose

Carl Pitzer - *Chair, NASTT PNW Chapter*

Driving South on I5 crossing the Ship Canal Bridge presents an all-encompassing snapshot of South Lake Union. Seven years ago this view would have been much different, an undesirable warehouse district. This area has rapidly developed into some of Seattle's most prized real estate thanks to an ever-changing army of tower cranes.

For the last four years Seattle has led the nation in total tower crane count, but today it finally has a challenger for the most tower cranes erected in the U.S. In Q2 of 2019, Los Angeles tied Seattle with 49 tower cranes. If Portland and Seattle team up to take on Los Angeles and San Francisco, however, the Pacific Northwest takes the tower crane cup. Tower cranes are a great indicator of construction and growth in an area. For us in the Pacific Northwest, we know this growth to be true both above the ground and below.

If you look hard enough you will see some impressive trenchless projects in the PNW starting soon. Seattle is gearing up for one of its largest CSO projects to date with the Seattle Ship Canal tunnel. Across the lake there are some large HDD projects and other trenchless projects on the horizon. Portland is planning on much needed upgrades to the city's water infrastructure which will utilize many tools in the trenchless toolbox. In Alaska, HDD is helping meet many infrastructure needs, and CIPP and sliplining continue to be methods of choice for rehabilitation. Many cities in Idaho are in a condition assessment phase to determine the state of local infrastructure.

Our mission is to be the premier resource for knowledge and education in trenchless technology. With the silver tsunami approaching, utilizing the knowledge we have as a group to enlighten the next generation will be necessary. Coupling that with record low unemployment makes generating interest and a passion for our industry even more important. The easiest way to do this is to engage with the up and coming engineers and contractors that are about to leave school and step out into the world.

The PNW may be the only NASTT region in North America without a sponsored student chapter. In keeping with our mission to be the premier resource for knowledge and education in trenchless technology and foster passion for the future of our industry, we have been building bridges (or "tunnels") with a large state college in our region. A faculty representative will champion the chapter and a student with a passion for trenchless technology has been identified to serve as the founding president. The national NASTT organization has been very supportive of this endeavor, and with our continued support I am confident the student chapter will take shape in the coming months.

The PNW-NASTT Chapter will continue to provide education as needed to all members and organizations in our region. Please let us know what your organization can benefit from and we will be happy to organize a Best Practices course or something similar.

In 2019 our board achieved perfect balance with representation from consultants, manufacturers, local government, and contractors alike. AJ Thorne from the City of Gresham transitioned from Secretary to Vice Chair. Heidi Howard with Staheli Trenchless maintains the position of Treasurer, and this year we welcome Glen Wheeler with J.W. Fowler as Secretary. Immediate past chair Brendan O'Sullivan continues to be involved and was instrumental in finishing our new website, which you can visit at pnwnastt.org.

I could write much more about the past, present, and future of our chapter, but the informative articles coming up deserve as much space as they can get. Thank you to all the authors who contributed. They are a small showcase of all the amazing trenchless work happening across the Pacific Northwest, though it's a little harder for the public to see these projects compared to those built by the tall standing tower cranes.

No-Dig 2020 in Denver

Craig Vandaelle - *NASTT Chair*

Hello, Pacific Northwest members! As the year marches along we're looking forward to the continued growth of the trenchless industry and our Society. The NASTT 2019 No-Dig Show held in the Chicago area this past March was a huge success with a record 200-plus exhibitors and over 2,000 attendees from all over the globe who came to experience the world-class technical sessions and networking events that our Show is known for.

NASTT exists because of the dedication and support of our volunteers and our 11 regional chapters. Plans are now underway for the 2020 No-Dig in Denver on April 5-9. Our No-Dig Show Program Committee members volunteered their time and industry knowledge to peer-review the 2020 abstracts and ensure that the technical presentations are up to the standards we are known for. Thank you to the Pacific Northwest Chapter members who volunteered for this important task: Dan Buonadonna, Jack Burnam, Scott Enbom, Michelle Macauley, and Brenda O'Sullivan.

The inaugural No-Dig North conference, October 28-30 in Calgary, offered a variety of learning and networking opportunities for trenchless professionals as well as those new to the industry. The conference included four NASTT Good Practices Guidelines Courses offered as pre-event options: HDD Good Practices, New Installation Methods Good Practices, Introduction to Trenchless Technology – Rehabilitation Good Practices, and CIPL Gas Good Practices. The courses include continuing education units as well as course materials to take back to the office for use on future trenchless projects.

The No-Dig North conference offered two full days of technical presentations and an exhibit hall bringing participants industry innovations for trenchless products and services. The exhibit hall sold out quickly – twice! No-Dig North was an outstanding opportunity to experience the latest and greatest in our growing industry and to network with peers. If you do business in Canada, you owe it to yourself to attend the next one.

Our continued growth relies on the grassroots involvement of our regional chapter advocates. Thank you again for your support and dedication to the North American Society for Trenchless Technology and the trenchless technology industry.

2020 WILD WEST SALOON

EDUCATIONAL FUND AUCTION

APRIL 6, 2020
5:30-7:00PM
DENVER, COLORADO

IN CONJUNCTION WITH THE NASTT NO-DIG SHOW

NASTT NO-DIG SHOW

For more information visit nastt.org/no-dig-show/auction

NASTT'S 19TH ANNUAL EDUCATIONAL FUND WILD WEST SALOON AUCTION & RECEPTION

Journey back to the Wild West and join us in the NASTT Saloon in Denver! The Annual Educational Fund Auction helps raise money for important causes. Since 2002, NASTT has raised nearly $1.2 Million and used those funds in support of our many educational initiatives. Due to your generosity, NASTT is able to provide targeted trenchless training and courses to the industry, publish resource manuals and sponsor university students' attendance to the NASTT No-Dig Show, as well as award scholarships.

EXCITING AUCTION ITEMS

Bid all day via your mobile device on great items like trips, event tickets, electronics, industry items and more!

COSTUME CONTEST

Calling all cowboys and girls, cattle rustlers, bar maids and saloon dancers! Come dressed in your Wild West finery for the auction's Ninth Annual Costume Contest! Cash prizes will be awarded!

50/50 RAFFLE

Win some cash for yourself and help our student chapters! The winning ticket will be drawn before the end of the auction and you must be present to win. The winner splits the cash pot with the students.

HAWAIIAN VACATION RAFFLE

The winner of this raffle will receive a dream Hawaiian vacation, $5,000 value! Tickets are $25 or five for $100 with a maximum of 1,000 tickets being sold.

Raffle generously sponsored by

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gastrock@coffman.com

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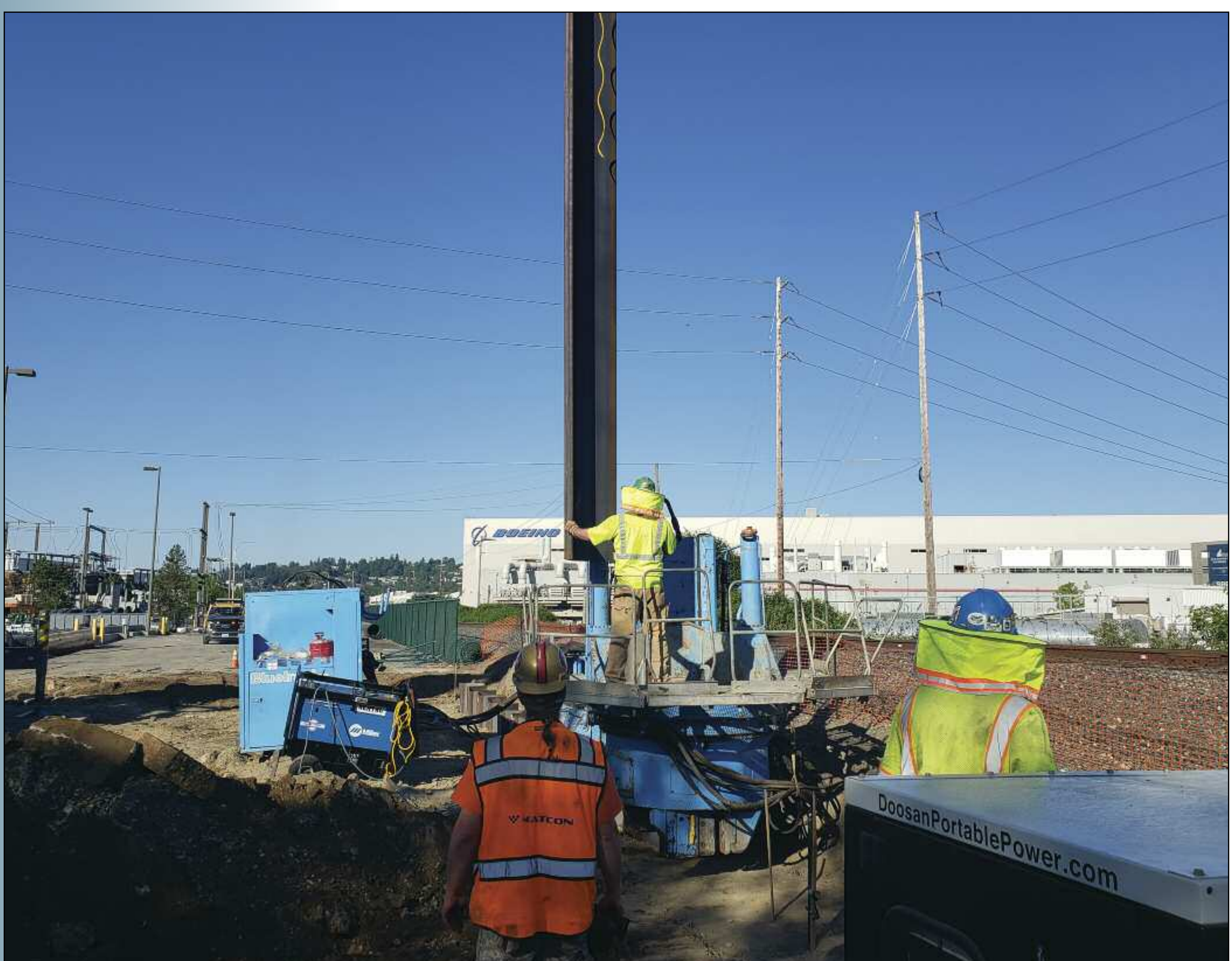
Brendan.O'Sullivan@murraysmith.us

Challenging Sewer Bypass and Rehabilitation of King County's 96-Inch-Diameter Eastside Interceptor

Brian Sliger, PE
Erik Waligorski, PE
Carollo Engineers

Matoya Darby
Bob Isaac
King County Wastewater Treatment Division

King County's Eastside Interceptor (ESI) collects the majority of wastewater flows from the Puget Sound cities of Kirkland, Bellevue, Mercer Island, Sammamish, Issaquah, New Castle, and Renton, and conveys it to the County's South Treatment Plant. This aging reinforced concrete pipe (RCP) interceptor was constructed over 50 years ago, and corrosion caused by hydrogen sulfide (H2S) gas has begun to take its toll on the pipe's interior. Sections of the pipe are experiencing mild to



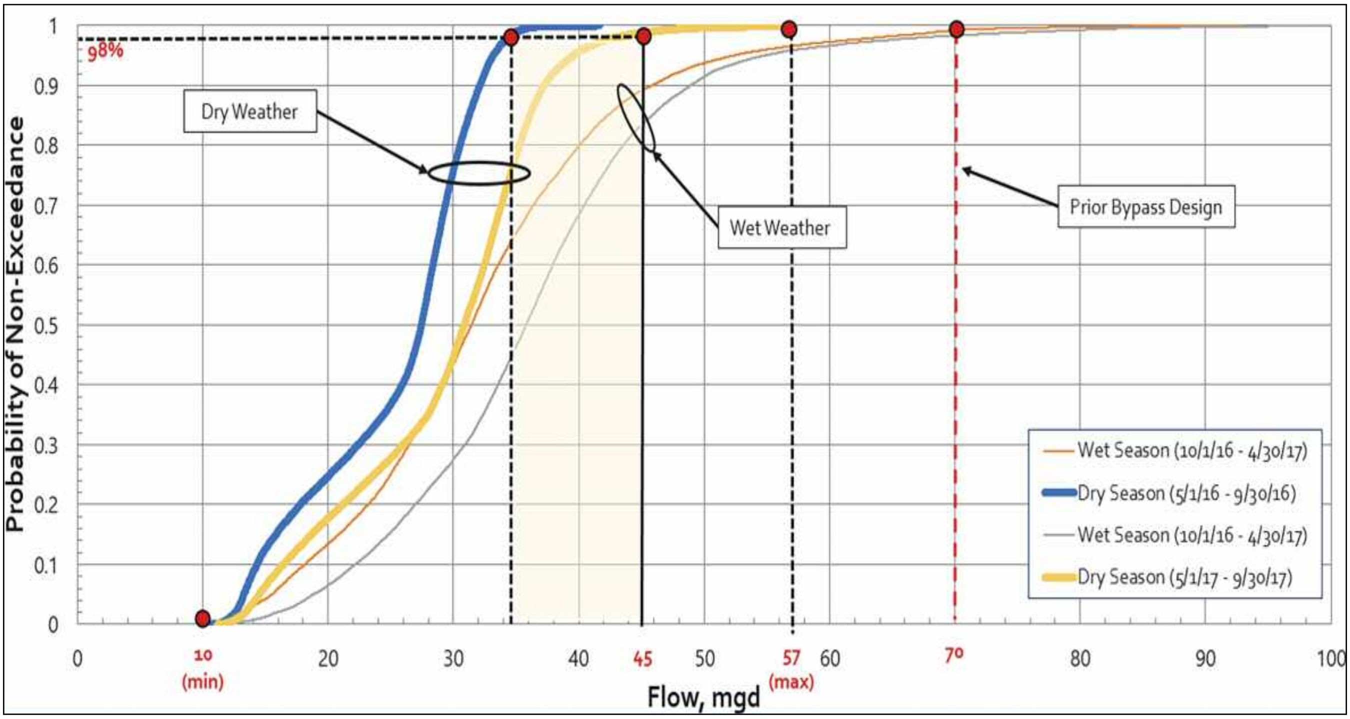


Figure 1. Exceedance, Dry and Wet Seasons

severe corrosion that causes the concrete interior to crumble, exposing rebar and affecting the structural integrity of the pipe. The County has developed a proactive approach to deal with the degradation of the pipe by identifying sections of pipe experiencing corrosion, prioritizing rehabilitation needs based on severity, and developing projects to carry out rehabilitation.

The Eastside Interceptor Section 2 (ESI2) Rehabilitation Phase II Project was developed to rehabilitate approximately 3,700 feet of a severely corroded 96-inch-diameter section of the ESI interceptor line located in Renton. This section of pipe runs through an urban area between Boeing's 737 commercial airline facility and the Renton Landing, a busy mixed-use development. King County performed an alternatives analysis that looked at various rehabilitation options for the project, including cured-in-place pipe (CIPP), spiral-wound PVC liner, and Linabond. Linabond was selected as the most appropriate rehabilitation method for this section of pipe as it maintained the greatest existing capacity.

Linabond is a corrosion-resistant polyvinyl chloride (PVC) liner that is applied to wall surfaces with a high-strength thermosetting polymer resin. The resin expands in an exothermic reaction to form a section of rigid cellular plastic that firmly bonds with the concrete. Prior to the application of Linabond, the concrete surface to be coated is hydro-blasted to remove loose concrete and debris. Temporary platforms are constructed within the pipe just below the proposed liner termination point to perform the work. Flows that are not bypassed are able to flow beneath this platform.

FLOW ANALYSIS, BYPASS PUMPING STUDY & CONSTRUCTION FOOTPRINT

The first step in the project design process was to determine the required bypass system capacity. The goal was to provide an optimized, cost-effective design capacity that covers the majority of recorded flows within the pipe. A previous study conducted by the County called for a bypass system capacity of 70 million-gallons-per-day (mgd). Carollo utilized two years of flow-monitoring data collected at the project site to conduct its own design capacity determination. Frequency curves were developed to assist in establishing the bypass pumping flow rate, and associated probability of exceedance during wet and dry seasons. The frequency curve in Figure 1 illustrates that the maximum recorded dry-weather flow of approximately 57 mgd was well below the previously proposed bypass flow of 70 mgd; 96 percent of the time, flow was below approximately 40 mgd. A design bypass capacity of 45 mgd was therefore selected, providing a 5 mgd factor of safety for the system.

The results of the flow analysis were then used to determine the various pumping requirements to be specified in the contract documents. Based on the flow analysis, the contractor would be required to pump a minimum of 10 mgd and a maximum of 45 mgd for 24 hours a day, seven days a week. Because there was a possibility of higher

flows, an emergency pipe evacuation plan and a means for allowing emergency flow release would need to be provided, as well as two standby pumps for mechanical redundancy. Due to the bypass suction pit's location near residential properties, the contractor was required to use electric driven bypass pumps and have standby noise attenuation to meet local noise ordinances.

These preliminary design requirements were used to move forward with the final design of the project. It was determined early on that the design of the bypass system would be left to the selected contractor, but some preliminary design and sizing of the system components were required to ensure all project elements requiring a long lead time would be in order and available prior to bid. The culmination of this preliminary design work was summarized in a Basis of Design Report that addressed the bypass intake pit design, the bypass pipe routing and discharge, and the work and staging areas along the alignment.

BYPASS INTAKE PIT DESIGN & EMERGENCY FLOW RELEASE

The bypass system's intake pit was located on an open piece of Boeing property through which the ESI2 pipe runs. To access the pipe, an approximately 10-foot-deep excavation, approximately 65 feet long and 20 feet wide, was dug to just below the crest of the pipe. This excavation faced some challenges as it was located in high groundwater and directly adjacent to a railroad spur track that transported Boeing 737 fuselages to the Boeing Renton plant. The existing pipe was also supported on piles due to poor soil conditions. To address these issues, the soils surrounding the pipe and excavation were chemically grouted to provide additional support for the pipe and aid in preventing groundwater leakage into the excavation. Steel sheet piles were hydraulically pressed-in to limit vibrations that could affect the adjacent railroad spur and pipe during the installation process.

A total of eight 12" x 12" skid-mounted pumps were required to meet the 45-mgd bypass capacity, bringing the total pumps installed to 10 including the two redundant pumps. After excavating down to the pipe, five 3-foot-by-1.67-foot coupons were cut from the top of the pipe for insertion of the ten 12-inch-diameter bypass pump suction lines. An additional 8-foot-by-5-foot coupon was removed for the installation of a custom-designed temporary bulkhead. The steel bulkhead consisted of two semicircular plates with guide rails anchored into the existing pipe, and two gate sections that slid down the center of the pipe along the guide rails. These gates were fitted with lifting hooks that allowed for their removal in an emergency situation.

BYPASS PIPE ROUTING & DISCHARGE

The preliminary design included an assumption for the bypass piping sizing of three 24-inch-diameter HDPE pipes. This was seen as a conservative sizing and used to develop design plans illustrating a piping route, potential utility conflicts, a trench design where required, and any restoration efforts that would be required. Topographic survey, existing utility research, and extensive potholing were conducted to aid this effort. The developed route included approximately 3,125 LF of overland pipe and 1,075 LF of trenched piping, for a total of 4,200 LF of pipe. These design plans were then used to facilitate project permitting and temporary easement acquisition.

During construction, the contractor proposed the use of a single 36-inch-diameter HDPE pipe and provided calculations and a route design showing the proposed piping would work. Custom-made utility crossing assemblies were constructed by the contractor to avoid utility crossing conflicts that were identified during design. After a thorough review the use of the single 36-inch HDPE pipe was deemed acceptable and was allowed.

A maintenance hole just downstream of the project limits was situated on a local, less-traveled street that could be closed for the duration of the project. To discharge the bypass flows the reducing riser was removed from the top of the existing maintenance hole, a temporary 48-inch riser section was installed, and the 36-inch bypass pipe was inserted directly into the 48-inch maintenance hole. The void between the pipe and the maintenance hole wall was temporarily sealed and a round cap was constructed around the existing pipe.

WORK & STAGING AREAS ALONG THE ALIGNMENT

Carollo worked directly with Linabond and associated contractors to determine the work and staging areas that would be required for the pipe preparation and Linabond installation process. A total of eight maintenance holes along the project alignment were identified for use as access points, equipment staging areas, ventilation installations, and odor-control installations. These areas were include on the design plans and the anticipated work and duration of work at each location was presented in a construction footprint technical memo. These documents were critical during permitting and property negotiations to provide a clear picture of the impacts to the community and property owners in the area, including traffic impacts, noise concerns, and potential odor issues.

The ESI2 Rehabilitation Phase II Project utilized flow monitoring data and statistics to provide an optimized bypass system that cut back on construction costs and overall project impacts. This optimized system design was utilized in the development of a sewer bypass plan that addressed as many issues as possible prior to construction. This up-front work minimized risks and project overruns, providing a smooth rehabilitation project that will extend the life of a critical piece of infrastructure for decades to come.

Unique Horizontal Drain Installation Under a Building Using Pilot Tube Guided Auger Bore Methods

Michelle Macauley
Macauley Trenchless

Steve Torgerson
Trenchless Construction Services

This case history presents a pilot tube guided auger bore (PTGAB) installation under an operational building. While the original construction included waterproof membranes, sub-slab drain tiles, and perimeter drains, subsequent additions to the building experienced reoccurring issues with flooding during storm events and times of heavy rainfall. Seven vertical wells were installed and worked to control the groundwater until 2010 when they became fouled and the basement flooded again. Additional wells with larger pumps/stainless steel screens were installed and worked until 2014 when the wells were again found to be heavily fouled.

A study was commissioned to develop a plan to provide long-term groundwater protection for the building while ensuring the uninterrupted operation of the facility. Two primary options were considered: installing horizontal wells under the building and installing more vertical wells. Ultimately, the preferred option was to install horizontal wells that would tie into a pump station while maintaining the existing vertical wells.

Previous explorations around the building indicated soil consisting of medium to coarse sand. Groundwater was known to be present at or near the elevation of the sub-basements (8 to 17 feet below ground surface).

TRENCHLESS DESIGN

Trenchless options were considered in order to maintain unfettered use of the building during construction. The project requirements included:

- 400-foot installation length,
- Both 6-inch and 10-inch diameter installations,
- No construction access inside the building during horizontal drain installation,
- Granular soils with a high groundwater level, and
- Installed well screen needed to be robust to allow for post-installation (long-term) cleaning.

Traditional well screens are installed in straight vertical bores that are over-sized and backfilled with gravel. This means screens are good in tension but not in compression or in curves. The two trenchless methods considered were horizontal directional drilling (HDD) and PTGAB. HDD is a common trenchless installation method for straight installations of horizontal drains into hillsides. However, there are challenges associated with using HDD to install drains under a building. These include:

- Bentonite used for HDD can foul the screens,
- Oversized borehole could cause settlement under the building,
- HDD locating equipment does not work well under reinforced concrete, and
- Well screens may break during pullback through the curved alignment of an HDD.

PTGAB is a 3-stage method to install straight pipes with tight tolerances and a small overcut (Figures 1a-c). The stages are:

1. Push the pilot tube along a straight alignment from the launch shaft to a reception shaft by displacing soil.
2. Use reusable steel casings with augers inside to push the pilot tubes along the established alignment and remove the pilot tubes from the reception pit.
3. Use the final pipe to push the reusable steel casing along the established alignment and into the reception pit.

For this project, a specialty stainless steel "pipe-based well screen" would be the final pipe. The benefits of using PTGAB to install the well screens include:

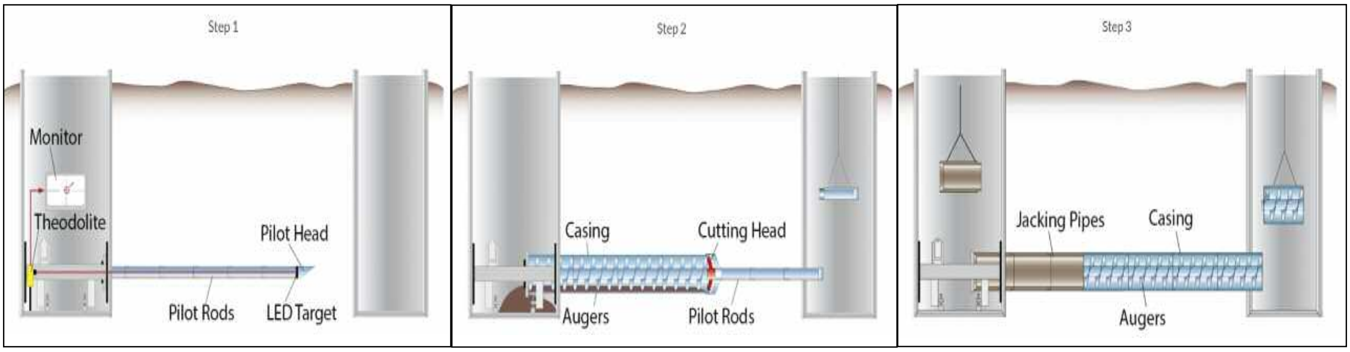


Figure 1. Pipe Installation

- All steering and guidance is located in the launch pit, so no access is needed over the alignment,
- It is a straight pit-to-pit installation method without curves, which would damage the screen,
- Drilling fluid is not required, and
- The over-cut is much smaller than HDD.

PTGAB was selected as the preferred trenchless option. The optimal well layout and orientation was a splayed array of four drains that extended under the building and drained back to a central pump station. A separate 10-inch drain line under the building would tie-in the existing vertical well system to the pump station. Figure 2 shows the orientation of the array and the pump station.

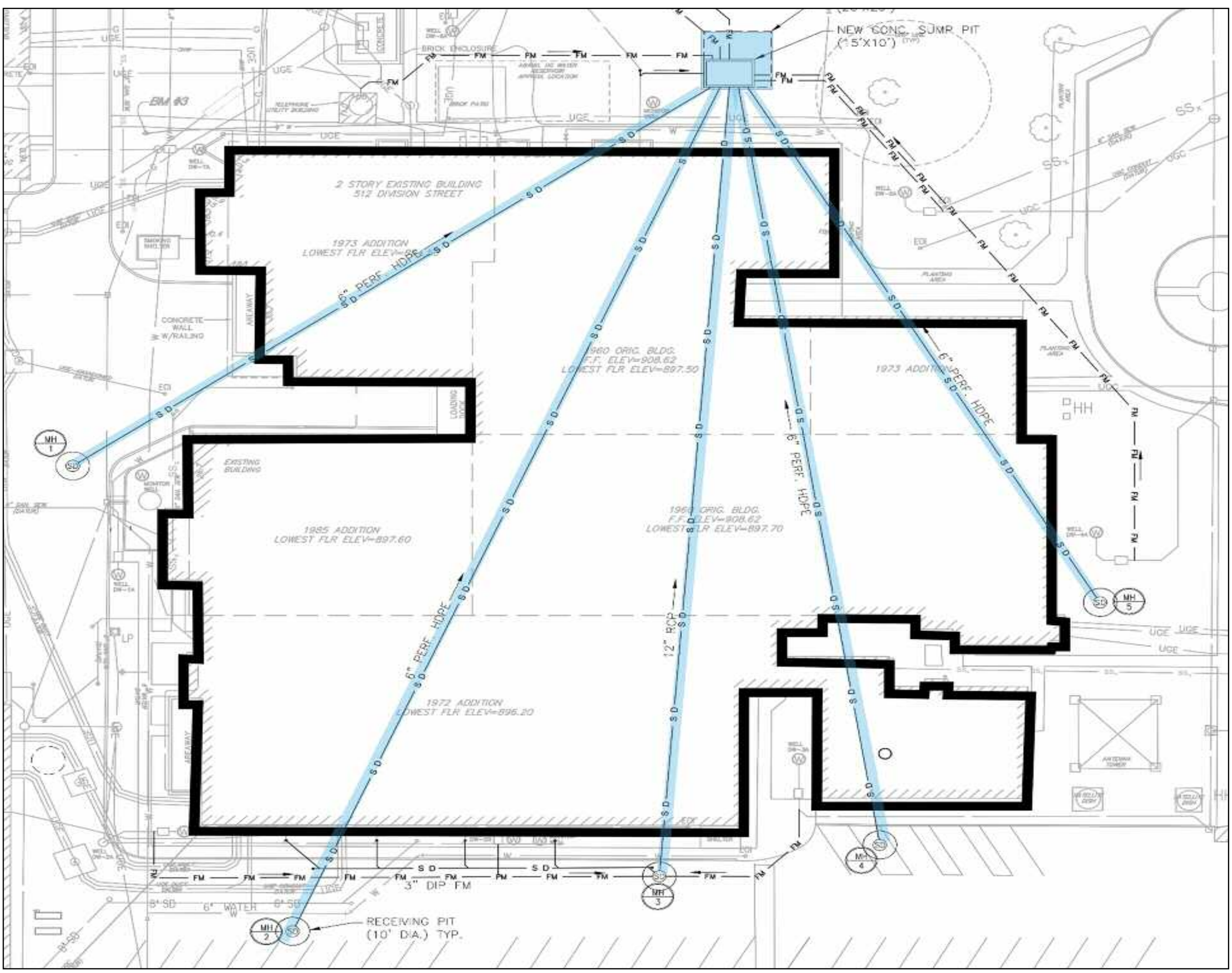


Figure 2. Pump Station

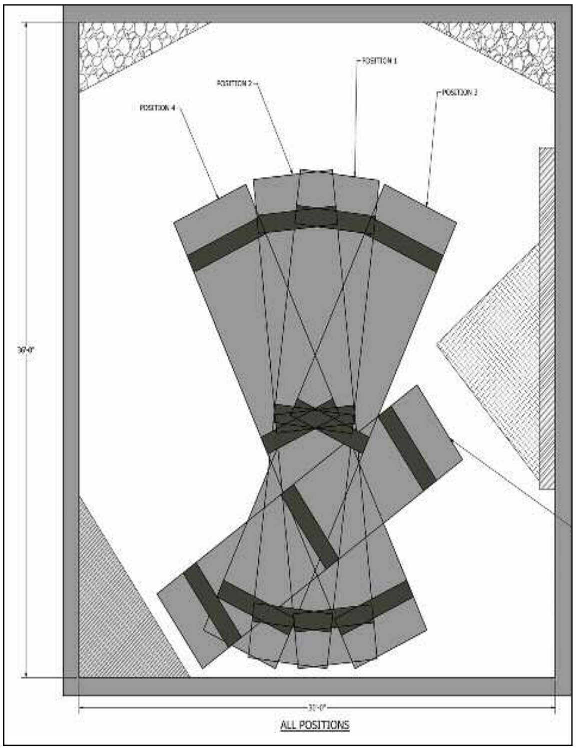


Figure 3. Orientations for Jacking Frames

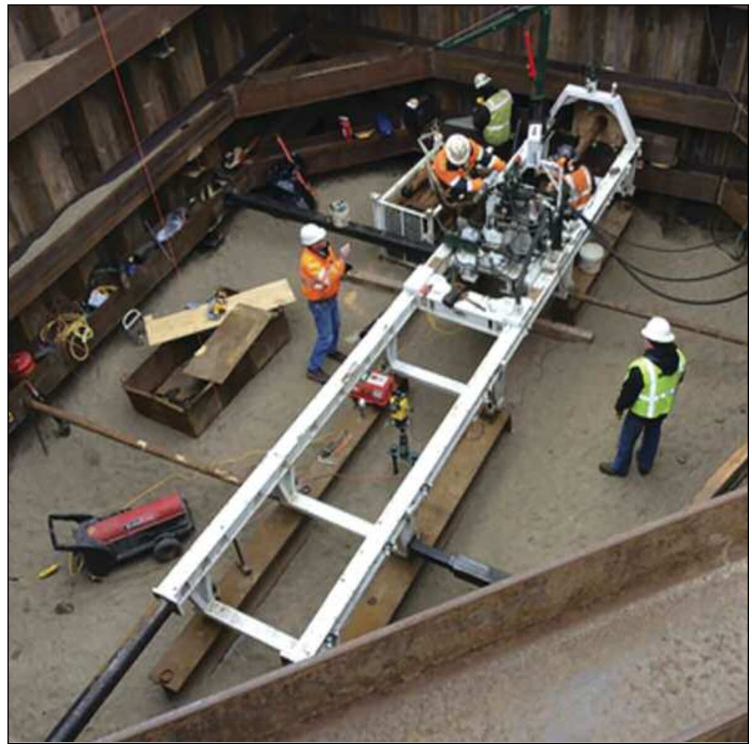


Figure 4. Storm Drain Installation

CONSTRUCTION

Extensive pre-construction submittals were required and included:

- The orientations, reaction walls, and bracing for the shoring including the multiple orientations of the jacking frame (Figure 3).
- Specialty well screen, adapters, transitions, and well screen protection had to be manufactured for this project and the submittal had to demonstrate adequate structural integrity.

Trenchless Construction Services (TCS) mobilized on November 26 and immediately faced an unexpected schedule challenge. A looming a government shutdown planned for December 22 would cause all construction to stop regardless of completion progress. The goal was to have the trenchless construction complete before the shutdown.

Challenges for the storm drain installation (Figure 4) included a lack of groundwater and encountering clay (rather than sand). It was presumed that since the building had been experiencing issues with groundwater and because additional wells had been required to dewater the shafts, that there would be considerable groundwater encountered during augering. However, the drier conditions, combined with the clay, resulted in the clay solidifying in the head, plugging the augers, and causing higher jacking forces. Since the storm drain wasn't a drain line, bentonite lubrication was approved for use, jacking forces decreased, and the installation was completed. The storm drain took six days total to install: two days to install the pilot tube, two days to auger the alignment, and two to install the 10-inch solid drain line.

Once the solid pipe storm drain was completed, launch shaft excavation continued down to the elevation of the drains. It took four hours to remove and replace the trenchless equipment, and about four days to excavate, rearrange the trenchless equipment, and resume trenchless installation. An additional waler beam set at the bottom of the excavation created a challenge because it set back the boring machine and exposed more length of drain pipe than planned (Figure 5).

The installation method for the horizontal drains was a hybrid pilot tube method where the pilot tube was used to set line and grade and then a specialty adapter transitioned the tail end of the pilot tube to the leading edge of the stainless steel, slotted drain pipe. This was an innovative approach which, according to the drain pipe manufacturer (Johnson Screens), had never been attempted. The manufacturer custom built an inverted pipe-based screen with a slotted pipe outside the screened section of pipe. The contractor tested the drain pipe prior to construction, indicating a compressive strength of 200,000 pounds.

The horizontal drains were installed from right to left (Figure 6). The first horizontal drain installed was Horizontal Drain 4 (HD4). HD4 was started on December 10th and installed without incident, taking three days to pilot and install the drain. HD3 was next and also installed without incident. It started on December 13th and took two days to pilot and install.

HD 2 posed a unique challenge. The additional waler at the bottom of the excavation offset the boring machine away from the wall, causing a long section of well screen to be non-supported. This caused the well screen casing to bend and cross-threaded the first 15 feet. Attempts at pulling out the well screen damaged it further, created a safety risk, and halted progress. Instead, TCS innovated an approach where the exposed tail of the horizontal drain was cut off, the threaded section of a pilot tube section was cut off (resulting in a blunt end), and the pilot tube was pushed inside the damaged portion of the horizontal drain. The cut-off pilot tube matched surprisingly well with the exposed inside portion of the cross-over adapter at the leading end of the horizontal drain. The pilot tube was then used to push the damaged sections of horizontal drain out along the original alignment. Once the damaged sections were fully removed from the alignment, new sections of horizontal drain were added at the launch shaft and pushed into position. An unexpected benefit was that the damaged section of horizontal drain worked like an HDD pre-ream, which allowed the second installation to push easily because it was being installed along a "pre- reamed" alignment.

While HD 2 was the most challenging, it still only took four days, starting on December 15th and finishing on December 19th. While the pilot tube had matched up well with the back of the adapter, the back end of the adapter was damaged because it had been made from mild steel instead of tool steel. Fortunately, Johnson Screen made a same-day repair on the adapter and construction continued.

Construction for HD 1 started on December 20th, a mere two days before the looming government shutdown. Applying the lessons learned from the other HD installations, this installation was completed in less than two days. The TCS crew drove off-site with 26 minutes to spare before mandatory shutdown.

Figure 5

Figure 6. Horizontal Drains Installed

The Use of Pipe Bursting in Alaska

The Rehabilitation of 34,000 Feet of Water Main in a Remote Location

Brian Gastrock, PE
Coffman Engineers, Inc.

Designing for remote locations in Alaska presents logistical challenges and high energy costs that require unique engineering solutions. At a remote site in Alaska located on the Aleutian Island chain, the installation of the existing water piping system occurred over numerous projects spanning the 1950s through the 1980s. The existing water mains generally consisted of 6-inch and 8-inch cast iron and asbestos cement pipe materials. Previous projects in the early 2000s successfully rehabilitated approximately 20,000 feet of pipe in the northern portion of the site using 8-inch and 10-inch HDPE pipe.

PROJECT DESCRIPTION

Coffman Engineers, Inc. (Coffman) provided engineering services on two separate projects. The first is a design-build project, the other is a design-bid-build. Both projects designed rehabilitation of the existing water main using trenchless pipe bursting methods. The rehabilitation included the underground utility design of the water main, with associated appurtenances such as fire water systems and control valves, and design of the temporary water system.

The design-build (D-B) project consisted of utilizing trenchless technology to pipe burst and replace approximately 4,000 linear feet of existing buried 8-inch nominal diameter asbestos cement and cast-iron water piping with 10-inch SDR 11 HDPE water piping. The design of the D-B project occurred in late autumn 2018 to meet the spring 2019 barge, with construction completed in summer 2019. The design-bid-build (D-B-B) project, currently in the final design phase and scheduled for construction in 2020 and 2021, consists of 29,000 feet of existing 8-inch and 6-inch water main pipes.

The project's remote access limited initial data gathering efforts only to obtain a design survey and perform field inspections. Geotechnical investigations were not obtained for this project due to the remote access and previous project information. Additional project challenges included existing record drawings having limited information on burial depth, location of valves and fittings, pipe material, repairs, and service connection sizes. In addition, multiple utility crossings (fuel, sewer, fire-protection, electrical, communication), both active and abandoned, at the project location were unknown and undocumented.

The entirety of this project includes two contracting mechanisms: design-build and design-bid-build. The two projects are separate contracts and have separate construction schedules. The D-B project was completed in less than 12 months from contract award to construction close-out. The D-B-B project is currently in final design phase and is anticipated to close out in 2021.

REMOTE CONSTRUCTION DESIGN CONSIDERATIONS

The site is a three-hour flight from Anchorage, the largest city in Alaska. There is no road access, and all materials must arrive by barge from Seattle or be flown in. Shipping and mobilization are significant costs and considerations to projects. The remote location of the project site requires advance planning of mobilization due to barge schedules and cost.

Field inspection of a water vault

Pipe bursting equipment in an access pit

Contractors generally mobilize materials from Seattle with the barge scheduled to leave Seattle in April. The site receives one scheduled barge per year, and additional barge shipments require significant cost and lead time to accommodate shipments. In order to complete construction projects on schedule, designs must be complete in February for D-B projects and November for D-B-B projects.

FIELD EVALUATIONS & DATA MANAGEMENT

Completion of the field inspections and survey took place in late 2018. The D-B contractor performed the survey for the 4,000 feet of water main in the project limits around the cantonment area. The D-B-B team performed the survey of the 29,000 feet of water main for the area along the project alignments. The client provided GIS information of the other existing utilities (communication, electrical, storm drain, etc.) to Coffman for inclusion into the basemap. Coffman merged the separate surveys and incorporated the GIS information to develop an installation-wide basemap with known infrastructure.

The engineering team was on-site during the survey to perform field investigations for the two separate projects. Coffman personnel aided the surveyors in locating the existing water valves, fire hydrants, sewer manholes, and other infrastructure pertinent to the design. Data gathered from the field inspections was essential to confirming existing pipe alignments and utility conflicts.

MATERIAL SELECTION & METHOD EVALUATION

The D-B project selected 10-inch HDPE pipe, which is commonly used in pipe bursting projects, for the new pipe. The projects from the early 2000s also used HDPE; the importance of maintaining uniform pipe materials for maintenance was an important factor for the client. The D-B-B project initially planned to use HDPE as the new product pipe for the same reasons as the D-B project. Early in the design, investigations found multiple sites with petroleum contamination. Through the design process, areas with known contaminated sites will have C900 PVC installed with petroleum-resistant FKM gaskets to resist leaching of petroleum compounds through the pipe.

The design of the D-B project uses pipe bursting; no additional trenchless rehabilitation alternatives were considered due to the tight design schedule. The contractor used a chain-drive static pipe bursting subcontractor to perform the work. The pipe bursting equipment used a 100-ton bursting rig capable of performing in excess of 250-foot pulls.

For the D-B-B project, in addition to pipe bursting, initial evaluation of rehabilitation alternatives included both sliplining and cured-in-place pipe (CIPP). The sliplining alternative was proposed for use on the abandoned-in-place 16-inch fire protection main that paralleled the 8-inch main along approximately 10,000 feet of the project alignment. Due to the possibility of the 8-inch main remaining in service during sliplining of the 16-inch pipe, sliplining the pipe offered the advantage of reduced need for temporary water.

Unknown crossing utility damaged during excavation, not the pipe bursting process

CIPP, also offered as an alternative, had the potential to reduce the number of excavations required. CIPP is capable of navigating pipe fittings so small service connections (less than 2-inch) can be reinstated internally without excavations. Also, CIPP presented limited contractor availability and the need for mobilization of specialized equipment, especially challenging in this remote location. The disadvantages of sliplining included the requirement of additional fittings and excavations to re-connect between the 16-inch and 8-inch water pipes, and the need to grout the annular space between the new pipe and host pipe.

Considering previous successful implementation on the projects completed in early 2000s, the owner requested the design team use pipe bursting as the rehabilitation method. This resulted in a reduction of surface disruption and faster installation.

HEAVE/SETTLEMENT & PULL CALCULATIONS

Most of the pipe for the D-B project was generally located in congested areas with other utilities and narrow utility corridors. The location of the D-B-B project is in more open areas with fewer utility and structure impacts. Due to the higher risk of impacting buildings and crossing utilities, we calculated surface heave and settlement for the D-B project using the Pipe Bursting Good Practices Guidelines, Second Edition 2011, by Dave Bennett, Samuel Ariaratnam and Kate Wallin. The calculations found the 8-inch to 10-inch bursting had the potential for up to 1.6 inches of surface heave and 1.0-inch of settlement.

The frictional component of the pulling force calculation was used to determine the anticipated minimum and maximum pulling forces for the longest run of pipe bursting. The calculations estimated the minimum pull force would be 78 tons, and the maximum would exceed 250 tons. A soil investigation was not part of the project, so soil conditions were estimated based on institutional knowledge of site conditions. The D-B project did not exceed the limits of the equipment (100 tons) and the longest pull was approximately 250 feet.

PROJECT RESULTS

This project gave the owner the flexibility of using both D-B and D-B-B contracting mechanisms. The D-B project was completed on time and on budget with only minor changes in the design. No significant claims or change orders were encountered during construction and the new water mains have increased reliability to the owner. The D-B-B project is scheduled to bid in late 2020 to meet the 2021 barge and will provide new water mains to the remaining areas of the installation. When the D-B-B project is complete, the entire water system will be rehabilitated with piping that meets current standards and needs of the installation.

Mark W. Hutchinson, PE
Jacobs Engineering

Maintenance Holes:
Your Lifeline to the Collection System

What do your manholes look like? Most people don't really know. They know where their worst problems are, because they may have videos of the pipes and a general idea of the manhole condition. They know a sudden sinkhole in a street or under a stream can be politically and financially costly. Interest in manholes and junction structures usually arises after a sinkhole develops, or when access is needed to complete pipe repairs.

The reality is that manholes and junction structures are your lifeline to the collection system and may be much more difficult to repair due to the pipe connections and irreg-

Comprehensive condition assessment requires entering the manhole.

Proactive condition evaluation and rehabilitation of manholes is wise.

ular manhole shapes. Add in high groundwater, depths over 15 feet, flowing soils, high traffic and overhead utilities, and they can be darn difficult and costly to replace. That's why proactive condition evaluation and rehabilitation before they fail is essential.

PROACTIVE OWNER

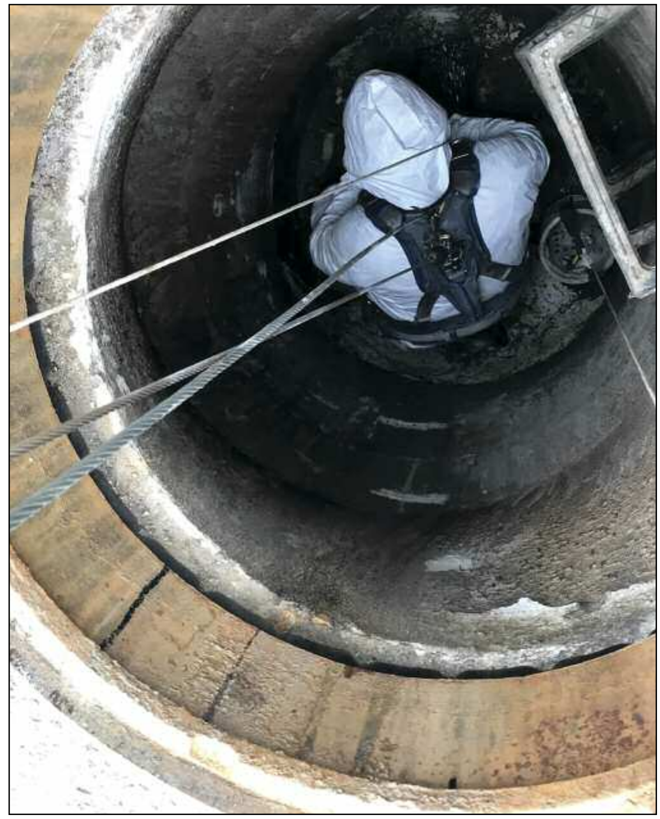
Eagle, Idaho, is one of the places where you want to live because of the beautiful golf courses, new homes, lush green lawns, sunny weather and nearby snow-covered mountains. Eagle Sewer District (Eagle) is a relatively new sewer district with a majority of their collection and treatment system built after 1975. So why worry about aging infrastructure? They don't, but they do take a proactive approach to caring for their system and their ever-increasing number of customers.

Lynn Moser, manager of the system, knows the day will come when they will not have new development to fund improvements and they will have to maintain the system on a limited rate-based budget. Lynn likes to make sure he is a good steward of the ratepayers fund by not spending money on transporting and treating infiltration that should be limited. Eagle pretreats effluent and transfers it to the City of Boise for final treatment. Paying for every gallon sent, Lynn doesn't want to pay for unnecessary treatment of ground water.

Trenchless technology is not new to Eagle. They replaced older concrete pipes using pipe bursting in 2013. They are now in the middle of a 24-inch, 5-mile-long horizontal directional drill (HDD) project to increase their future capacity and reliability. During routine CCTV (Eagle does their own CCTV), they noticed infiltration at the base of a manhole that had been previously grouted, as well as inflow and infiltration (I/I) in another. That's when Lynn contacted Jacobs Engineering, which has a standing contract for treatment plant engineering, and asked if they could look into the problem.

Understanding the potential generators of H2S and infiltration is key to tailoring the investigation. At Eagle the process started with a review of plan and profile drawings and other available system data to determine drivers for the infiltration and structure corrosion. Having a list of potential repair methods prior to investigation was also key to making sure the right information is gathered for solution development. Information via phone or email cannot replace a site visit with the owner to thoroughly understand their collection system, history of repairs, access, safety/traffic control requirements and the social needs of the community.

Prior to the site visit, we knew 18 manholes were downstream of two pumping stations, a potential generator of H2S gas. A very steep sloped pipe (up to 8%) down a hillside was also identified as a potential generator of H2S gas. During the site visit a few manhole covers were removed to get an initial idea of structural conditions. We learned that carbon filters had been installed under some manhole covers to limit odors for nearby residents and were likely limiting air flow, a contractor had pipe burst through manholes without installation of manhole adapters, and a local firm had grouted the manholes numerous times to stop infiltration. The manholes ranged from 10 to 18 feet deep, making it difficult to ascertain the condition of the lower portion of the manholes. However, we found the concrete in the upper portion of the manholes to be soft enough that I was able to write my name in it. Afterwards, the grouting contractors were contacted and information was gathered from workers that had been in the manholes before to help tailor the information.



CARS field technicians are lowered into each manhole to record condition information and take photos.

TEAMWORK AND SAFETY

As stated before, Eagle performs their own CCTV inspection. They were asked if they wanted to do the investigation (with Jacobs supplying detailed inspection forms). They declined and indicated their desire to have someone with greater experience investigate the manholes. Our Condition Assessment and Rehabilitation Services (CARS) field investigation group, led by Dan Hegwald, was contacted for an estimate, which was later accepted. Eagle offered to do the traffic control when the field investigation team, Isaiah and Billy, showed up with their "inspection-ready" fully equipped field vehicles. I accompanied them as senior engineer. Not on-site during the inspections but participating were other NASTT members from NASSCO, Armorock and other Jacobs offices.

Safety was the first order of business, ensuring confined space procedures with appropriate PPE and traffic control were in place prior to performing investigations. Once the site was safely secured the team began collecting the desired information and thoroughly documenting:

- Manhole dimensions
- Flow level of all incoming and outgoing pipe
- Condition of frame and cover, chimney, cone or corbel, walls, benches and channels, and pipe connection seals
- Active or evidence of infiltration

This manhole looks good from above, but closer inspection uncovers problems.

- Cracking
- Depth of corrosion
- Concrete hardness

MANHOLE INSPECTION

There are many moving parts to inspecting a manhole. CARS field technicians were lowered into each manhole where they recorded condition information and took photos as the Jacobs Engineer observed, asked questions, and considered rehabilitation approaches. The manholes looked fine from top-side but as technicians probed, scraped and measured, they found active or evidence of infiltration around the pipe seals and up to 3 inches of soft deteriorated concrete on the manhole benches and walls.

Our experience has been that manholes usually fail at a pipe connection, failed drop connection, or area around an incoming pipe. The manholes in Eagle were also found to be a problem in the area around the pipes connection. Grout around the incoming pipes was soft from 1 to 3 inches deep with groundwater infiltration entering around the PVC and HDPE pipes.

Corrosion from H2S was found to be a problem in this system, starting at the bottom of the system with less than 1 inch of concrete loss. As we worked our way upstream to the base of the hill and pump station discharge, more wall loss, up to almost 2 inches, was evident. Next to the pump station discharge, 3 inches of the 5-inch-thick manhole wall was missing. This problem was not evident from top-side. The 15- to 18-foot-deep manholes appeared to be in good to fair condition with smooth gray concrete with little corrosion until a scape test was performed and softened concrete sluffed from the wall like toothpaste or soft plaster. Of particular interest was the pattern of deterioration. It was found to be most severe near the outgoing pipe on the downstream wall, mirroring the air flow.

From the investigation, a report followed in a couple of weeks with data forms, pictures and information to classify the manholes. Of course, the design engineer already had this information plus firsthand observations to develop a rehabilitation plan moving forward. The report was used in preliminary conversations with Northwest Linings and manhole rehabilitation vendors, and then follow-up with contractors who had been working in the area.

The design was not strictly developed from the collected data. Eagle sewer district customers were factored in to limit disruption to a local golf course, school traffic, and their quiet country living. Eagle's preference was to rehabilitate all the manholes with a trenchless solution.

The design that followed included lining a few manholes to prevent further deterioration, rebuilding a majority of the manholes with polyurethane, abandoning five manholes , and installing polymer or fiberglass inserts in a few manholes that were too deteriorated to be lined. All manholes had benches rebuilt based on level of corrosion, including two manholes that had previously been lined.

Key Points: Unlike most pipe, you can't fully see the level of corrosion in concrete manholes; you have to enter the manholes and do testing. Teamwork produced a solution fitting local needs and resources. Investing in a trenchless solution now is allowing the owner to maintain a lower sewer rate structure and public support in the future.

Design Considerations for Large-Diameter Pipe Ramming Installations

Glen Wheeler
James W. Fowler Co.

Luke Erickson
McMillen Jacobs Associates

Pipe Ramming is a common trenchless method across North America for installing steel casing conduits in mid to short tunnel drive lengths. As this method gains popularity, advances in techniques and technologies are being employed across the industry to install larger and longer casings. As the size and length of crossings increase, there are key design considerations that must be considered for a successful project. These design considerations include ground conditions, the forces required to install the casing, break-out and face stability, hammer tensioning system requirements, and cone adapter design. This article presents a summary of the key design considerations for large-diameter pipe ramming installations and describes how these considerations were addressed. Two recently completed large-diameter pipe ramming projects by James W. Fowler Co. (JWF) are reviewed along with the lessons learned.

PROJECT DESCRIPTIONS

OHSU Block 28 and 29 Design Build Tunnel Project: As part of the expansion of the Oregon Health and Science University (OHSU) in Portland, JWF partnered with McMillen Jacobs Associates (MJA) to develop a pipe rammed installation of a 12-foot-diameter tunnel beneath an active roadway and light rail tracks to install a pedestrian and utility tunnel from the basement of a new building being constructed into an existing parking structure. The trenchless crossing was approximately 70 feet long and was located approximately 30 feet below the ground surface.

Ryan Creek Fish Passage Project: The project included the installation of two 10–foot-diameter fish passages on Ryan Creek beneath Highway 101 in northern California to mitigate potential impacts to Coho Salmon during the construction of the Willits Bypass by the California Department of Transportation. The fish passages were each approximately 170 feet long and utilized pipe ramming techniques for 136 feet of each crossing while the remaining 34 feet utilized cut-and-cover methods. The fish passages were located approximately 30 feet below the roadway surface.

KEY DESIGN CONSIDERATIONS

There are five key design considerations that must be addressed for the successful installation of a large-diameter pipe ramming project. These design considerations are discussed below followed by a discussion of how each design consideration was addressed on each project recently completed by JWF.

1. Ground Conditions

Pipe ramming is best suited for very soft to medium-stiff silts and clays or loose sands above the groundwater table. Installations below the groundwater table may be possible in cohesive soils with low permeability and minimal groundwater head. Pipe ramming below the groundwater table in sands or gravels can be problematic because groundwater can easily flow through the soil resulting in flooding and loss of ground. Dense sands and gravels are less favorable as larger installation forces are required to advance the pipe.

A. OHSU Project

Ground conditions consisted of structural fill adjacent to the existing subsurface parking structure and native soft silts adjacent to the new building. The crossing was located below the groundwater table, however dewatering required for the new building excavation was in place and lowered the groundwater to below the crossing elevation. No problematic ground conditions were anticipated or encountered during construction.

B. Ryan Creek Project

Ground conditions on this project consisted of medium dense to dense poorly graded sand with gravel and silt above the groundwater table. No problematic ground conditions were anticipated or encountered during construction.

2. Installation Forces

For large-diameter pipe ramming projects, the soil friction and weight of the soil increases rapidly as the pipe is advanced due to the surface area of the pipe, and the installation force required to advance the pipe can increase rapidly. Periodic removal of soil from inside the pipe can reduce installation forces; however, larger-capacity ham-

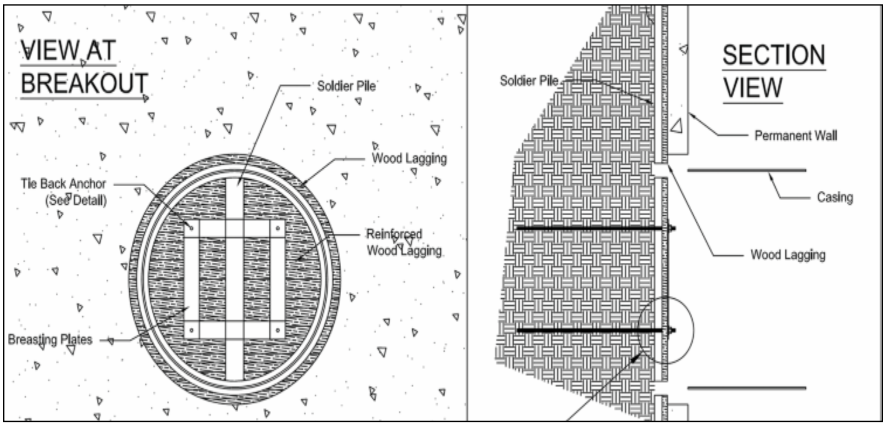


Figure 1. Preliminary Headwall Concept, OHSU Project

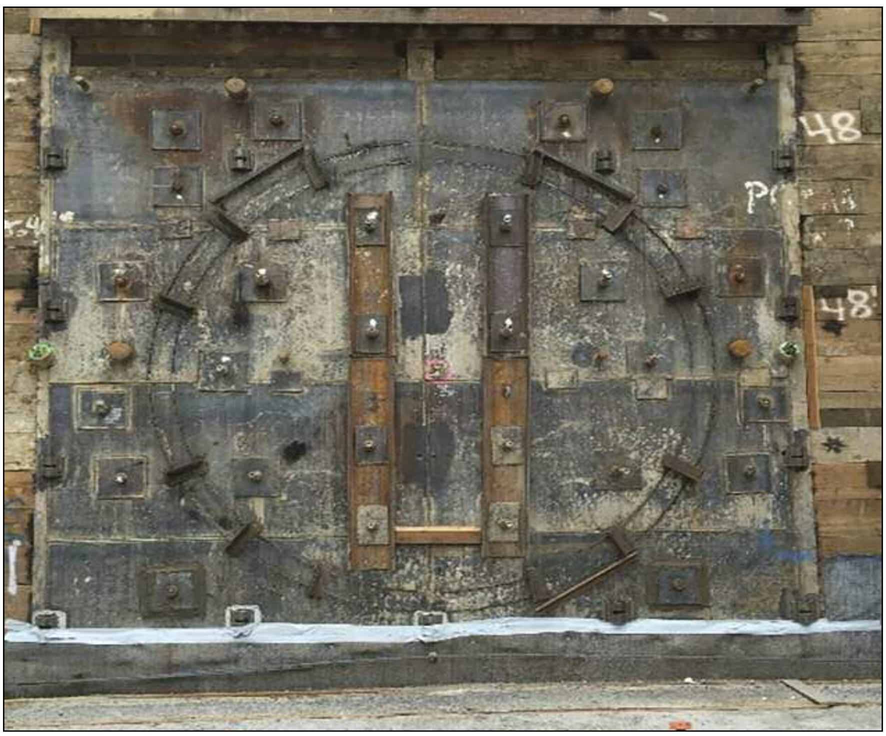


Figure 2. Headwall, OHSU Project

mers are typically necessary to advance large-diameter long installations. These large-capacity hammers are larger in size and require more staging area for setup and operation, and require increased thicknesses and/or size of components to prevent damage to the system and casing.

A. OHSU Project

Due to space limitations within the excavation support system, JWF elected to use a IHC S-90 hydraulic hammer. A larger hammer with more capacity would have been preferred, but this was the largest size hammer that would fit within the excavation. 1.25-inch-thick Permalok pipe was selected to resist the anticipated installation forces and prevent damage to the casing during installation.

B. Ryan Creek Project

The pipe ramming operation was staged at a portal for this project so there were less space limitation for staging construction. JWF elected to use a larger, more powerful IHC S-150 hydraulic hammer due to the longer length of the installations and larger anticipated installation forces. The steel pipe used was 1.5-inch-thick Permalok pipe to resist the larger installation forces anticipated.

3. Break Out & Face Stability

Maintaining face stability of the excavation is critical for preventing loss of ground. While breaking into the ground, a penetration must be made through the headwall or shoring system so that the pipe can be advanced into the ground. For large-diameter installations, the span and height of the penetration is large so the soil will typically not stand without support. Once the casing has been advanced far enough into the ground, face stability can be achieved by maintaining a soil plug within the casing as it is advanced.

A. OHSU Project

To maintain face stability while breaking out of the shaft, MJA and JWF developed a soil nail and steel plate tunnel interface system as shown in Figure 1. This system utilized soil nails to support steel plates within the vicinity of the tunnel horizon. A thin cut-out was made in the steel plates to allow for the pipe penetration and the circular plate shown in Figure 2 remained in place inside the casing to support the soil. Once an adequate soil plug was developed inside the casing, the steel plates and soil nails within the tunnel horizon were removed.

B. Ryan Creek Project

Based on the success of the OHSU tunnel interface system, the Ryan Creek tunnels utilized a similar system consisting of soil anchors supporting steel plates (refer to Figure 3). The main difference was a reduced number of soil anchors were utilized, which reduced removal time and improved schedule.

4. Tensioning System

As hydraulic pile driving hammers are typically utilized in a vertical system when installing vertical piles, the weight of the hammer is necessary to cock the internal anvil mechanism. When using these ham-

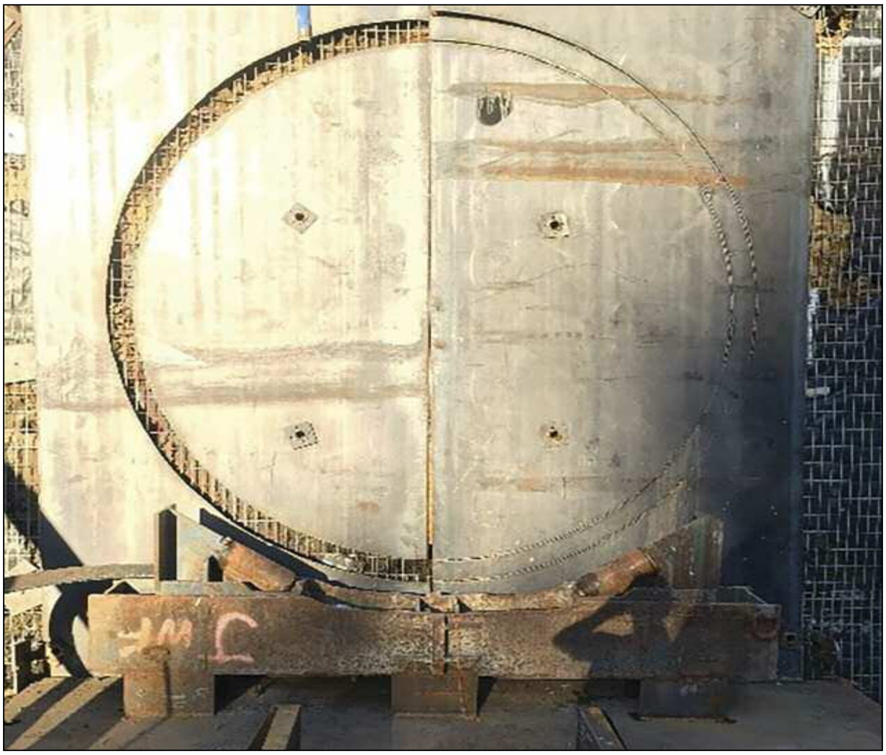


Figure 3. Ryan Creek Headwall & Face Stability

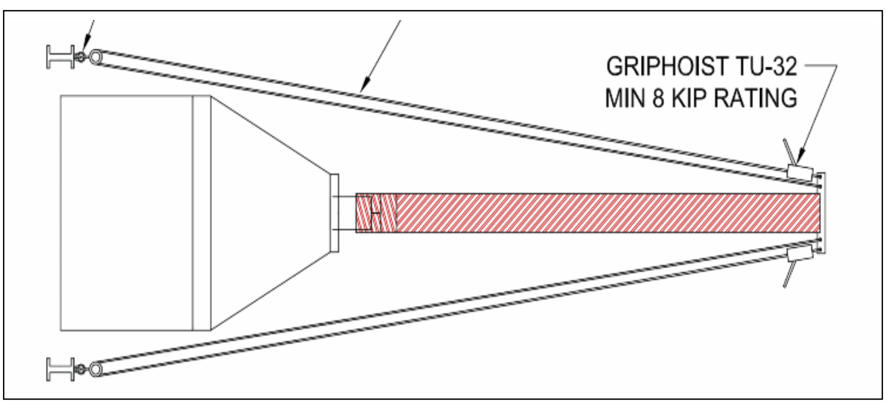


Figure 4. OHSU Tensioning Layout

Figure 5. OHSU Tensioning Photo

mers in a horizontal application (e.g. pipe ramming), the same force is necessary to cock the anvil. To achieve this, a tensioning or thrusting mechanism must be created to provide a compression force equal to or greater than the weight of the hammer as the pipe is advanced.

A. OHSU Project

To cock the IHC S-90 hydraulic hammer that was used on the project, approximately 23 kips was required. The system to achieve this consisted of two man-powered griphoist units set up with pulleys anchored to the steel piles of the excavation support system to provide the necessary force to the rear of the hammer (Figures 4 and 5). The tensioning system worked during construction; however, the man-powered griphoist units had difficulty keeping up with the penetration rate, resulting in some loss of production.

B. Ryan Creek Project

The use of the IHC S-150 hammer required a more rubust tensioning system compared to the OHSU project. After the issues witnessed with the grip hoists on OHSU, a winch system was used to maintain the required tension on the system and maintain the pipe penetration rate. This system comprised a 12.5-ton winch and pulleys. The pulleys were attached to the ground anchors since there were not steel piles to anchor. During the first drive, an anchor point which was not pull-tested failed during ramming. A revised system which utilized a point attached to the casing had to used to complete the drive resulting in a slower production rate. For the second drive, the anchor points were reinforced, resulting in no anchor failures and increased production.

5. Cone Design

The "cone" or upsizing head, serves to transfer energy from the anvil of the hammer to the trailing edge of the steel casing which is being installed. This cone is crucial to maintaining proper energy transfer, and is typically the most susceptible to damage dur-

Figure 6. Tensioning System, Ryan Creek Project

ing the pipe ram installation. Cone angles vary depending on project needs; however, smaller/flatter cone angles prove more effective. Larger/steeper cone angles reduce energy transfer efficiency and create stress/strain concentrations. These stress concentrations can lead to fatigue in the steel and cracking of the welds.

A. OHSU Project

Due to shaft constraints, the ramming cone for the OHSU project was limitedin length, resulting in a cone angle of 31-degrees. The steep geometry of the cone led to stress concentrations during the OHSU drive. These cracks occurred at the larger end of the cone where it adapted to the casing. The cone had to be repaired multiple times during construction which resulted in significant down time during construction.

B. Ryan Creek Project

After some cracking of the OHSU cone was witnessed during pipe ramming, JWF determined that more analysis of the cone was necessary before fabrication. Thanks to stress/straing simulations provided by IHC, weak points were indentified which were reinforced with thicker material and gussets. Extra space in the launch pits also allowed for a cone angle of 25-degrees, which resulted in better energy transfer and less material fatigue.

LESSONS LEARNED & CONCLUSIONS

On the OHSU project, the confined space available for pipe ramming operations required shorter pipe lengths which restricted the size of the hammer that could be used and required the use of a steeper cone. The manually operated tensioning system also struggled to keep up with casing advancement rates, which resulted in lower advance rates for the casing installation. Based on the lessons learned from the OHSU project, JWF was able to make modifactions to their pipe ramming set up for the Ryan Creek Fish Passage project which improved the pipe ramming operation and production rates.

Key takeaways and lessons learned include the following:

- Adeqate face support at headwall/shoring penetration to prevent loss of ground and subsequent settlement.
- Headwalls or shoring systems must be robust and designed for earth loads as well as anchor loads for tensioning systems.
- Tensioning system needs to be able to apply constant tension and be able to keep up with advance rates.
- Use smaller/flatter cone angles for cone geometry to prevent damage to the cone and to promote efficient energy transfer to the casing.

Emergency Stormwater Repair in Mill Creek, Washington

Laura Anderson
Akkerman Inc.

Northwest Boring Co. Inc. (NWB) of Woodinville, Washington, was subcontracted by Shoreline Construction for an emergency replacement of the City of Mill Creek's failed 30-inch CMP stormwater pipeline that had been causing flooding in the suburban city just north of Seattle.

The need for the stormwater system's repair became apparent when a sinkhole appeared in December 2017 between the Sweetwater Ranch and Douglas Fir neighborhoods. Temporary repair work was conducted, but another sinkhole developed in the same location just one month later. After inspection, it was determined that a failed coupler and damage to the 36-inch corrugated metal stormwater pipe was the root cause.

Because the City of Mill Creek had declared this an emergency project costing less than $300,000, a public bidding process was not required. Shoreline Construction was selected as the contractor and subcontracted the trenchless work to NWB.

The alignments scheduled for replacement were positioned within a narrow easement between two homes at 11-foot depths in difficult ground. With minimal real estate, the depth of installation and geological conditions, NWB knew that their guided boring would be an ideal installation choice for the new stormwater connections.

NWB used their Akkerman GBM 4800 Series Jacking Frame with a high-torque casing adapter attachment for auger boring. The combination made it possible to install the

pilot tube passes and 10-foot pipe with the torque and jacking force of an auger boring machine but within a smaller shaft. The design utilized one launch shaft to initiate the runs from both directions, which further reduced disruption to residents' properties and saved on project costs.

The ground conditions present were glacial till with rock, typical for this region. This ground cannot be displaced with a standard pilot tube steering head, so NWB arranged to use special tooling for up to 12,000 psi UCS ground. The drill bit of choice, the Rock Drill Adapter with TriHawk® drill bit, led the pilot tube passes which established the 140-linear-foot and 110-LF alignments at the necessary line and grade for gravity flow. Simultaneously, a soil-appropriate lubrication regime was applied to flush the excavated cuttings back to the launch shaft for removal.

Crews then prepared to direct jack the 110-LF and 140-LF 36-inch steel casing. In advance of the casing, NWB launched a guide rod swivel with a 36-inch cutter head which matched the 36-inch casing diameter. The swivel portion of the tooling absorbed the auger rotation while the cutter head, equipped with durable carbide gage cutter bit tooling, excavated the difficult ground. This second pass was completed with the guide rod swivel with cutter head for both stormwater sections.

The alignments were then finished with 27-inch Vylon carrier pipe positioned inside the casing and connections to the existing infrastructure were made.

From start to finish the entire project was finalized in just under a month, resolving the City's dilemma in a timely manner with minor intrusiveness to residents.

Contractor:

Northwest Boring Co. Inc.

Location:

Mill Creek, Washington

Owner:

City of Mill Creek

Completion:

May 2018

Ground conditions:

Glacial till with rocks

Pipe:

36-in. OD steel casing,

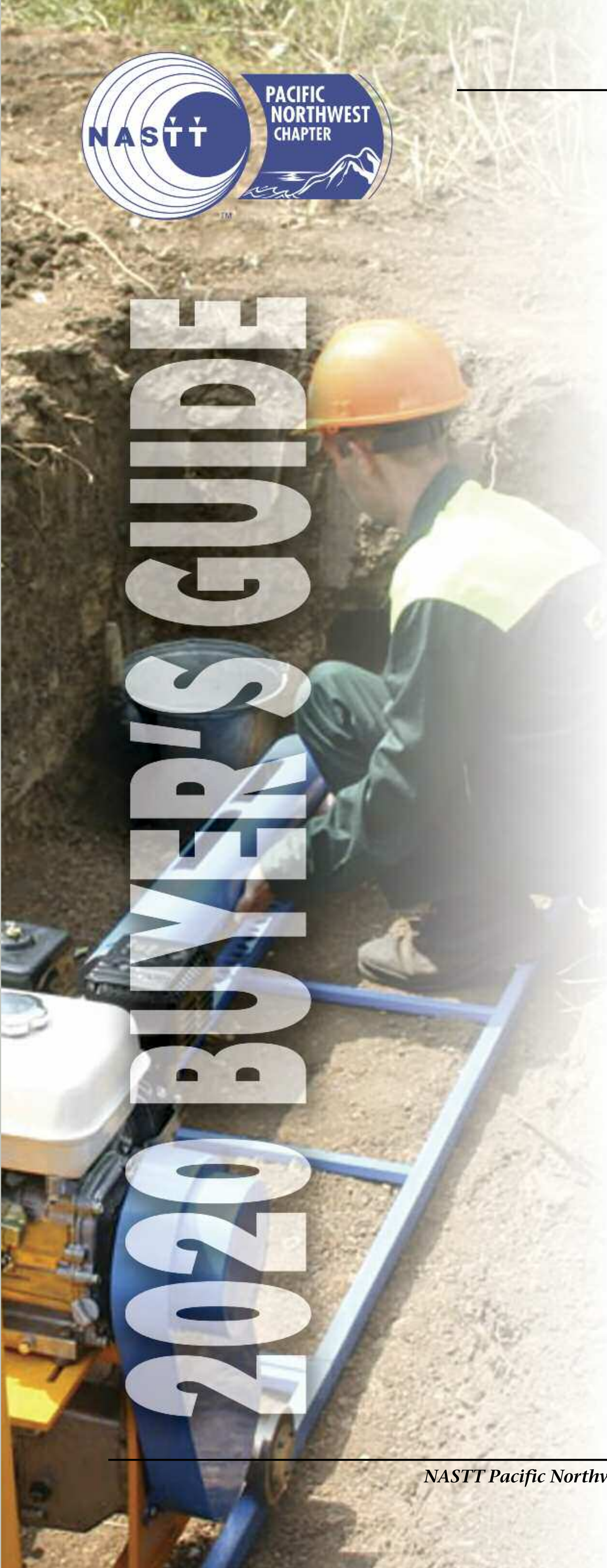
27-in. Vylon carrier

Total Length/Longest Run:

250 linear feet/140 LF

Akkerman Equipment:

GBM 4800 Series, High-Torque Casing Adapter (HTCA), Guide Rod Swivel (GRS) 50 36,-in., Rock Drill Adapter with TriHawk® drill bit



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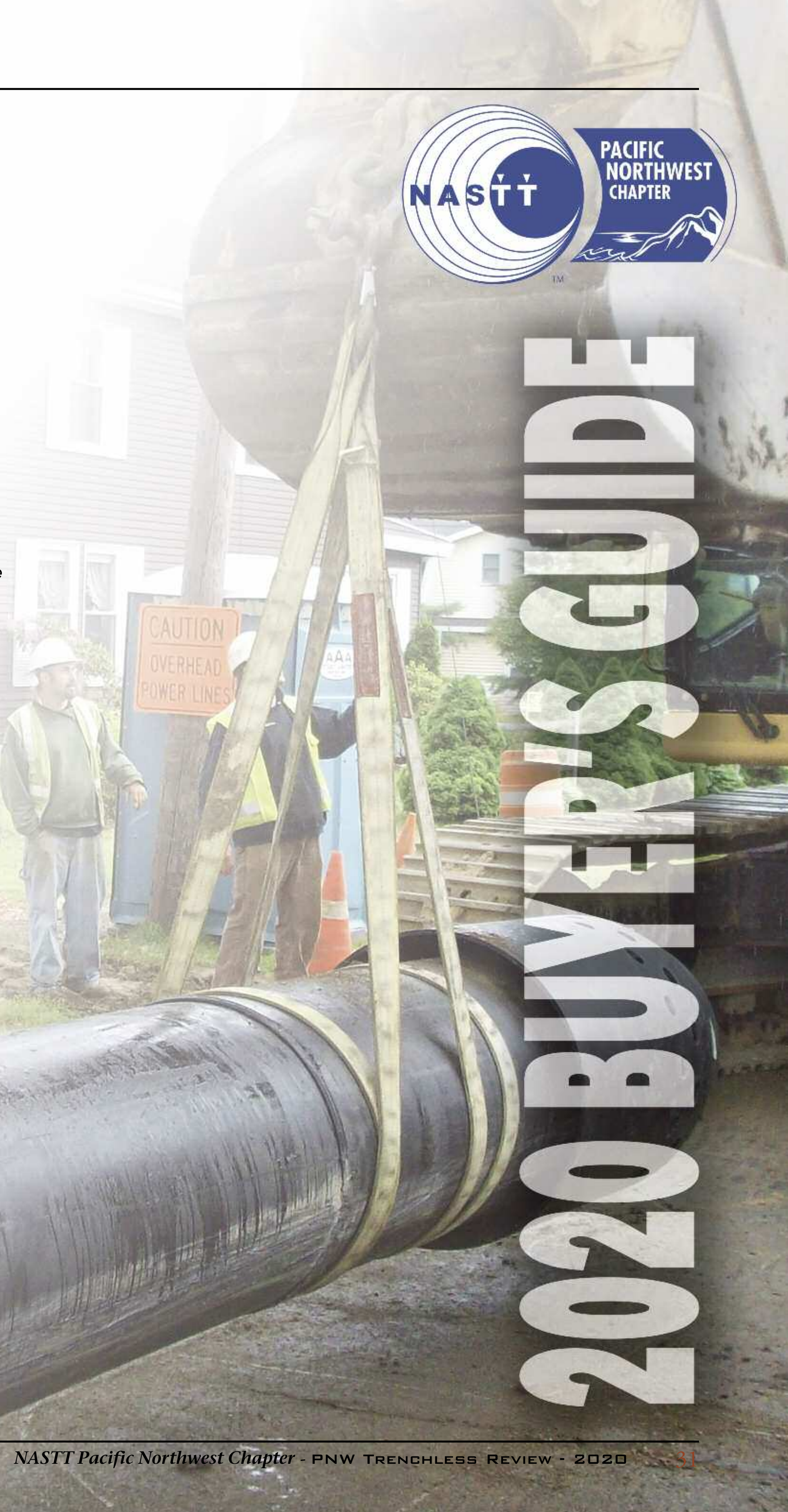

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Engineering Judgement When Evaluating Allowable Annular Pressure

Jake Andresen
Staheli Trenchless Consultants

INTRODUCTION

The Delft Equation is a solution developed by the Delft Institute to estimate maximum bore pressure (P_{max}) which can be sustained by a given soil formation during a horizontal directional drilling (HDD) installation. The most common form of the equation is a solution for P_{max} with seven corresponding input values: pore pressure, vertical effective stress, initial bore diameter, maximum plastic radius, soil shear modulus, soil friction angle, and soil cohesion (Luger and Hergarden, 1988).

There are three components to effectively using a tool such as the Delft equation to model the borehole conditions during drilling: 1) a thorough understanding of the model assumptions, sensitivity, and contribution of the input parameters, and any empirical components; 2) understanding of geotechnical principles necessary to apply the model to a complex three-phase matter with appropriate conservatism; and 3) understanding of the relation between the actual condition during drilling and assumptions.

The Delft model assumptions are well documented by Keulen (2001) and Neher (2013), and this article documents an approach to developing further understanding of the relationship between the calculated solution and the input parameters.

SENSITIVITY

A single equation with seven input variables, the sensitivity of the Delft equation for a given parameter is more complex. By building upon the work done by Staheli et al. (2010), a sensitivity analysis was developed to evaluate not only the relationship between the calculated Pmax and the input parameters but also the relationship between the parameters themselves. For instance, the governing parameters of the Delft model in a shallow bore may be very different from the governing parameters of a deep bore. The effect on P_{max} was by varying the parameter of interest at different depths, soil consistencies, and bore size. The evaluated parameters include soil shear modulus (G), soil cohesion (c), soil friction angle ϕ, and maximum radius of the plastic zone ($R_{p,\,max}$). The results are summarized below.

Angle of Internal Friction

The sensitivity of the internal angle of friction was varied from 20 to 42 degrees. The values of total density and cohesion were held constant at 110pcf and 100psf respectively. The variation of internal friction angle was performed at values of shear modulus ranging from 100ksf to 1500ksf. Figure 1 shows the sensitivity of internal friction angle with shear modulus equal to 100ksf, plotted against the P_{max}. The relationship is captured well by a linear regression, indicating a linear relationship, with an R2 value of 0.99, which was found to be true for both very soft soils (low shear modulus) and stiff soils (high shear modulus). The parameters were varied in a model simulating both a moderately deep bore (30 feet depth) with diameter 8-inches and a shallow bore (5 feet

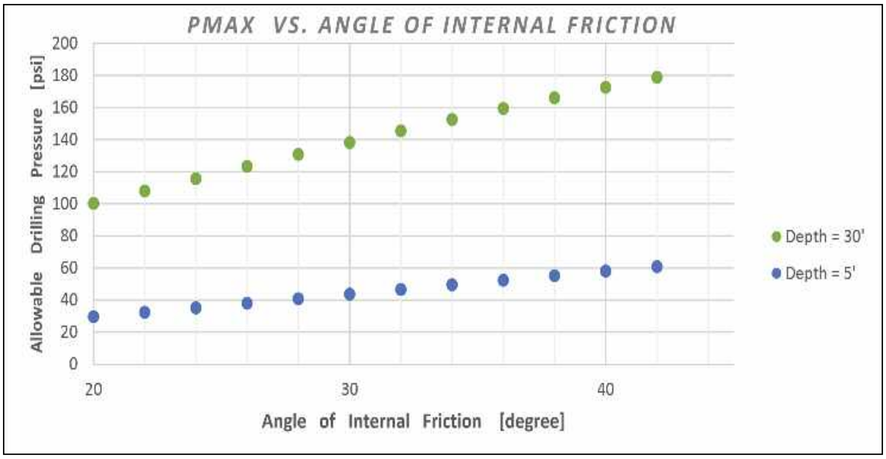

Figure 1. Variation of internal angle of friction against P_{max}

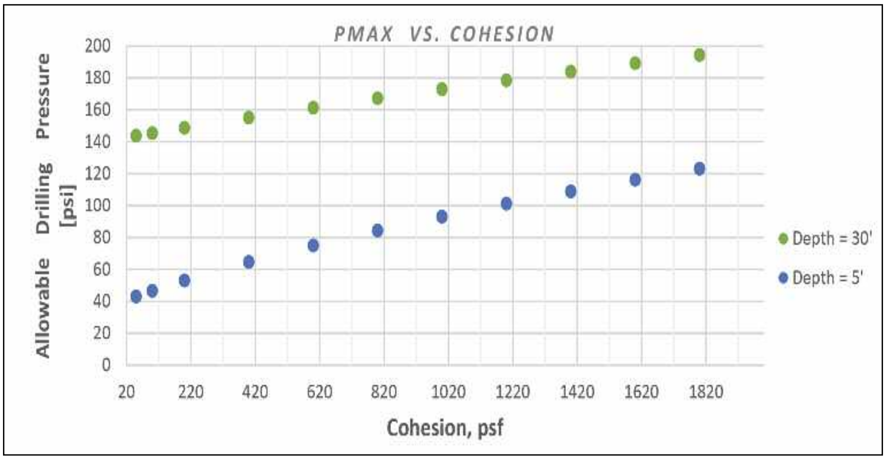

Figure 2. Variation of cohesion against P_{max}

depth) with diameter 4-inches.

Cohesion (Undrained Shear Strength)

P_{max} was found to correlate linearly when the value of cohesion was varied from 0 to 1800 psf. The values of total density and internal friction angle were held constant at 110pcf and 32 degrees respectively. The parameters were varied for relative values of soil stiffness (shear modulus) ranging from 100 to 1500ksf. All regressions showed R-squared values of 0.99 or greater.

Shear Modulus

The shear modulus is a parameter with a wide range varying up to 2 orders of magnitude. The inherent uncertainty often associated with the soil shear modulus input used in the Delft Equation is described by Asperger and Bennett (2011). By varying shear modulus while holding all other values equal, the variation in the calculated P_{max} value has been developed for bore depths of 5, 30, and 60 feet below grade. Figure 3 shows that though each plot has the same general shape, the result is that depth has a large impact the which range of G has the greatest impact to P_{max}. whereas little change is noted in P_{max} when ranging shear modulus from 100 to 200 ksf in a 5-foot deep bore (10% or less), the change in the calculated P_{max} is 35% for the same variation in G in a 60-foot deep bore. Further, the calculated P_{max} reaches a limiting value with respect to G at much lower values at a shallow bore when compared to a deeper bore.

Maximum Radius of the Plastic Zone, $R_{p,max}$

Staheli et al. (2010) established that P_{max} is non-linear with respect to $R_{p,max}$ and reaches a limiting value at $R_{p,max}$ inputs of between 2 and 3 bore diameters for the bore analyzed (median input parameters for a 30-foot-deep HDD bore). A similar sensitivity analysis on the relationship between P_{max} and $R_{p,max}$ was developed with varying conditions as summarized in Table 1. Based upon this analysis, the number of bore diameters were determined at which the calculated P_{max} reaches 90% of the maximum value (corresponding to $R_{p,max}$ = bore depth). The input parameters which were not varied were normalized for an 8-inch diameter bore in soil formation with 110pcf unit weight, 32-degree soil friction angle and 0 pore pressure. For example, for a soil formation with 500psf cohesion, 100,000psf shear modulus, and height of soil cover equal to 10 feet, the calculated P_{max} achieves a limiting value at 7 bore diameters.

CONCLUSIONS AND APPLICATION

The following conclusions may be gathered from the sensitivity evaluation of the Delft Equation:

- P_{max} is sensitive to $R_{p,max}$ for values of 10-feet or less and models of very stiff soils with high values of cohesion will be sensitive to $R_{p,max}$ only for values of 2 to 5 bore diameters. Within this range, the model is very sensitive to Rp,max. This matches findings from Staheli (2010) and Staheli (1998).
- The relationship between cohesion and P_{max} is linear regardless of soil stiffness.
- The relationship between internal friction angle and P_{max} is linear regardless

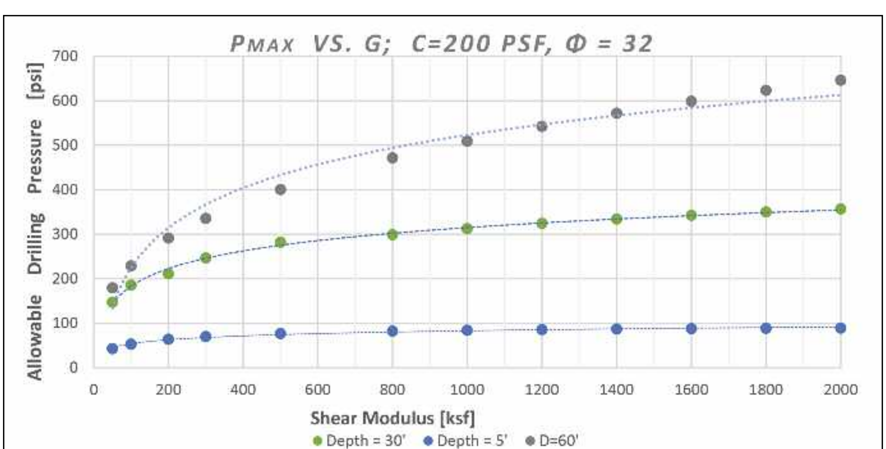

Figure 3. Variation of shear modulus

Cohesion	Shear Modulus	$H_s = 10'$	$H_s = 30'$	$H_s = 60'$
C = 50 psf	G=100000	12	12	12
	G=500000	5	13	16
	G=1000000	6	10	14
C=500 psf	G=100000	7	11	12
	G=500000	5	12	16
	G=1000000	3.5	8	13
C=1000 psf	G=100000	5	10	11
	G=500000	5	11	15
	G=1000000	3.5	8	8
C=2000 psf	G=100000	5	9	10
	G=500000	4	10	8
	G=1000000	3	8	11

Table 1. Plastic radius required to achieve 90% of the maximum allowable pressure (normalized to D_0 = 8 inch)

of soil stiffness.

- The relationship of P_{max} to shear modulus is non-linear and the impact of shear modulus to the calculated P_{max} value is dependent upon the bore depth and the range of the relative values of the shear modulus on the range of potential values.

As indicated by Staheli (2010), the parameters with the greatest effect on the outcome of the Delft Equation are shear modulus, height of soil (effective stress), height of water, and cohesion. However, for shallow bores, the equation has decreased sensitivity to shear modulus.

An interesting note related to the Delft Equation and $R_{p,max}$: $R_{p,max}$ is essential to the closed form solution because using this surface, the static equilibrium equations required to solve for P_{max} can be solved. However, as discussed above, when using the Delft Equation, the $R_{p,max}$ value is not a great contributor to the equation output for values greater than 10 times the bore diameter and depending upon the soil conditions and bore geometry, the limiting value may be reached at as little as 2 to 3 bore diameters.

Approaching the Delft Equation with a full knowledge of its overall application to the bore being designed is an important component of hydrofracture risk analysis and the characteristics as documented above as well as the assumptions inherent in the equation should be incorporated into any model being developed.

REFERENCES

Asperger, M., Bennett, D. (2011) “The Search for G: Selecting Shear Modulus for Use in Hydrofracture Analysis”, North American Society for Trenchless Technology, No-Dig Conference 2011, Washington, D.C.

Keulen, B., Arends, G., Mastbergen, D.R. (2001). “Maximum allowable pressures during directional drilling focused on sand”, Delft Geotechnics Thesis Paper.

Luger, H.J., Hergarden, J.J.A.M. (1988). “Directional drilling in soft soil; influence of mud pressures”, Proceedings of the International No-Dig Conference, Washington, D.C.

Neher, M. (2013) “HDD Hydrofracture: Roots of the Model We Use (But Don’t Understand)”, North American Society for Trenchless Technology, No-Dig Conference 2013, Sacramento, CA.

Staheli, K., Price, C.G., Wetter, L., (2010), “Effectiveness of Hydrofracture Predictions for HDD Design”, North American Society for Trenchless Technology, No-Dig Conference 2010, Chicago, IL.

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