ABSTRACT: The Board of Public Utilities (BOPU) for Cheyenne, WY faces the same issues with their infrastructure that many mid-size utilities across the country do. Population growth and age have left portions of the distribution system both undersized and in poor condition, resulting in inadequate capacity and increasing maintenance requirements. For the last several years, BOPU has been evaluating innovative, cost effective, and less disruptive solutions to rehabilitate old pipe lines. One solution has been the use of static pipe bursting to increase the flow area and replace some sections of their existing distribution water lines that are in need of rehabilitation.

BOPU’s rehabilitation experience is unique for several reasons. First they utilize contractors and a design-bid-build procurement to perform the work, as opposed to self-performing, relying on specification and contractor capabilities to perform the work. They have also found those types of projects that make sense for pipe bursting as opposed to typical dig and replace installation, including location, pipe material, existing pipe sizes and constituent reaction to pipe bursting instead of open cut, street work. BOPU has also been gathering pull force data applied to the pipe during the installations, which lends further understanding of the pipe bursting process and its effect on the product pipe installed.

1. INTRODUCTION

The City of Cheyenne was founded in 1867 when Union Pacific Railroad (UPRR) construction crews wintered along the banks of Crow Creek, a little stream flowing onto the plains from the Rocky Mountains. Fort DA Russell, later renamed F.E. Warren Air Force Base, was also established just west of the city to provide protection to the city and railroad workers. Cheyenne is the Capital of Wyoming and has a population of 59,500 people per the 2010 census. Cheyenne is situated at an elevation of 6,100 feet, along the extensive and fast-growing Front Range Urban Corridor, approximately 100 miles north of Denver.

Cheyenne's first water system was owned and operated by the UPRR. In 1882, the city council laid the groundwork for what is now Cheyenne's water system. Construction of Cheyenne's first water treatment plant was completed in 1915, and some of the city's existing potable water infrastructure is more than 100 years old. In 1943, the City Council established the Board of Public Utilities (BOPU) to manage and control the city's water and sanitary sewer system.

Crow Creek provided plenty of fresh water for the railroad camp and the town that grew up around it. From the date of Cheyenne’s founding, the headwaters of Crow Creek, about 35 miles west of Cheyenne, had been Cheyenne’s sole source of water. Although Crow Creek was adequate for the area's initial water needs, Cheyenne's geographical location in relation to large water supplies required the development of larger and more consistent water sources. Between 1902 and 1930, five dams were constructed on three branches of Crow Creek, west of Cheyenne. These
Dams provide for collection of 4,000 acre-feet of water annually under average rainfall and snow pack conditions. Nearly 10,700 acre-feet of water can be stored in the five local reservoirs.

In the 1930’s, the city supplemented its surface water supply by developing an underground water supply. Today, the city maintains 36 ground water wells that range from 170 to 500 feet deep. The wells can provide Cheyenne with 3,000 to 5,500 acre-feet of water annually and are used primarily to supplement water supply during peak demand periods. Cheyenne has rehabilitated a number of wells in the past 20 years. During peak day demands for drinking water, the City’s water wells are capable of producing 9 to 11 million gallons per day (MGD).

With the steady growth of the city during the 1940’s and 1950’s, it was evident that Cheyenne needed to develop an additional source of water. Because water rights in the North Platte River drainage were already appropriated during normal flows, Cheyenne looked over 115 miles farther west, to the headwaters of the Little Snake River in the Sierra Madre Mountains on the western slope of the Continental Divide.

Cheyenne acquired sufficient water rights to the Little Snake River, a tributary of the Yampa River, in the Colorado River drainage in the late 1950’s. The presence of several large mountain ranges between the Sierra Madres and Cheyenne made the actual delivery of this water to Cheyenne cost prohibitive. An intricate trans-basin diversion plan was developed whereby water collected from the Little Snake River drainage could be traded for water from the closer and more deliverable Douglas Creek drainage located in the Snowy Range about 75 miles west of Cheyenne. The Little Snake River water is diverted to the North Platte River in exchange for water from Douglas Creek, a tributary to the North Platte River. Stage I of the plan was completed in 1965.

Figure 1. The figure shows the general service area for the City of Cheyenne BOPU. The blue line indicates the service area boundary. The ‘WAFB’ is the F.E. Warren Air Force Base location.
As Little Snake River water is released from Hog Park Reservoir and eventually flows into the North Platte River, Cheyenne is authorized to divert water from the Douglas Creek drainage into Rob Roy Reservoir. Water released from Rob Roy Reservoir travels to Lake Owen, then by gravity about 50 miles via a 36” diameter pipeline where it is released into the Middle Crow Creek drainage, and into Granite and Crystal Reservoirs, two of the five existing reservoirs in the Crow Creek drainage.

The following are some current statistics regarding the BOPU and the customers they serve in Cheyenne, WY:

- Customers - 22,600
- Approximate raw water mix: 70% surface water, 30% ground water
- One Water Treatment Plant (WTP), with a capacity of 35 MGD
- Average WTP production: Summer 16 MGD, winter 7 MGD
- Two Water Reclamation Facilities (WRF)
- WRF Capacity: Crow Creek WRF - 6.5 MGD, Dry Creek WRF - 10.5 MGD.
- Eight reservoirs, 36 municipal wells.

Here is a breakdown of the water pipeline system that allows the BOPU to serve its customers:

- Raw Water Pipelines - 956,825 feet
- Reuse Mains - 70,127 feet
- Transmission Mains - 1,319,760 feet
- Distribution Mains - 2,085,296 feet

Providing clean, abundant, fresh water in the Front Range corridor can be a difficult task, particularly in the face of tremendous growth potential. As can be seen, water sourcing can be extremely expensive and physically daunting in the geographic location of Cheyenne. Therefore, protecting that water once it has been brought into the delivery system is critical, and this is why BOPU maintains a keen interest in its delivery system.

### 2. REHABILITATION PROGRAM

Cheyenne is facing the problems common to many older cities with their water and wastewater infrastructure. Some of the pipelines in their system are over 100 years old (see Figure 2). BOPU has taken steps over the last several years to develop a comprehensive, proactive capital improvement program to replace and improve the bulk of its aging water distribution and wastewater collection infrastructure.

Figure 2. Typical older cast iron infrastructure present in the BOPU distribution system.
Cheyenne’s aggressive capital improvement or "rehab" program for water involves the replacement of strategic portions of the distribution water main each year on a prioritized schedule. Comprised primarily of cast iron, ductile iron, and steel pipe with mains typically from 4 to 8 inches in diameter, many of the system’s older lines are not only being replaced but also upsized to 8 inches or larger to increase fire protection and improve overall water service including quality and flow. The selection process of which lines will be replaced within each fiscal year, which runs from July 1st through June 30th, is complex and involves the cooperation of several local and state agencies.

BOPU began their list of replacement projects several years ago by first identifying and ranking all of the system’s water mains through its water distribution crews and foreman who identified and reported problem areas. These findings were initially recorded in a series of mapping books. The formalized map books became the starting point for analysis of the system’s weaknesses and strengths. Knowing that easily accessible detailed mapping data would be critical in their task, the BOPU embarked on an aggressive GIS-based database program to track all of the system mains, meters and maintenance histories. For this, the BOPU utilizes mapping software by ESRI. BOPU also attempts to coordinate certain projects with the City of Cheyenne Engineering Department as well as the Wyoming Department of Transportation (WDOT) to minimize disruption and unnecessary costs.

The City Engineering Department and WDOT supply BOPU with a list of the projects that they have planned for street improvements or replacements. The BOPU then conducts an assessment of the water and sewer mains that are running beneath these roadways. The departments do their best to coordinate efforts so that if roadways and pipes are in need of replacement or improvement, construction efforts are performed simultaneously. In most cases, the schedules are well timed with each other, but the BOPU will conduct replacements in problem areas that cannot be delayed to ideally match up with the other agencies’ scheduled programs.

BOPU's rehab projects are either designed by a regional engineering firm or by the BOPU's own engineering staff. All projects require survey and geo-technical data collection that are bid out to local or regional service firms. After the survey and geotechnical findings are submitted, the engineering team will begin modeling that includes sizing of the pipes and input of the models into the agency GIS system. In-house decision making and analysis is conducted to determine whether upsizing is required in addition to the standard replacement. AutoCAD Infrastructure Design Suite software programs are then utilized to create the site or project designs. The designs undergo an in-house review as well as a review from the Wyoming Department of Environmental Quality (DEQ) and Cheyenne Engineering Department. Once approved, the design and project requirements are published for public bidding.

For the last 8 years, the water rehab program budget averaged $1.2 million per year, and an average of 5,800 linear feet of pipe was replaced per year. Replacement pipe material can be either Class 52 ductile or AWWA C900/905 PVC at the contractor’s discretion and preference, with PVC almost always being the pipe of choice. The BOPU has established a level for their rates to insure that capital improvement projects can be completed.

Although the BOPU cannot dictate a contractor’s construction methods or practices, there are several requirements and common procedures that are part of every project. The city does dictate how many blocks that the contractor may have open at any one time. It is typically limited to one to two blocks, each block having an average of 20 homes. Prior to any replacement work, the contractor will begin to plan and construct a temporary water service for the area.

Once the temporary water service system is operational, the replacement process will commence. If the contractor is using ‘dig and replace,’ direct bury as a rehab method, pea gravel will be introduced to fill the trench to provide a base for the new pipe. Once in place, a compactor will compress the surrounding soil around the newly installed pipe before the asphalt can be replaced. After the new water main is installed and prior to being activated, each new line is hydrostatic tested, chlorinated, flushed to remove chlorine, and bacteriological analysis is conducted. After all tests are passed, the individual property service lines are reconnected to the new main and the temporary system is removed.
3. PIPE BURSTING AS A REHABILITATION ALTERNATIVE

As part of a continual improvement process, BOPU is constantly evaluating new technologies to improve construction operations and efficiencies, reduce cost, and to decrease disruptions and inconveniences to their customers and the general public. Over the past several years, various no-dig technologies have been evaluated and used, with varying degrees of success. Some of the technologies that have been used for both water and sewer rehabs include cured in place pipe (CIPP), slip lining, cement grout/polyethylene liner, and pipe bursting.

One no-dig technology that BOPU has successfully employed with increasing frequency is pipe bursting. BOPU first tried pipe bursting on the Financial Year (FY)-2007 water rehab project. It was used in three of six areas that were rehabbed. Because of the success of the initial pipe bursting project, it has been used more frequently in annual water rehab projects. For the FY-2012 water rehab project, it was used in 4 of 5 areas. The last 2 years, BOPU has specified fusible polyvinylchloride pipe (FPVCP) for its water rehab pipe bursting jobs.

When BOPU first began to evaluate pipe bursting as a rehab alternative, the engineering department reviewed available data, researched contractors, equipment, and pipe, and contacted other municipalities that had used pipe bursting to get their feedback. In the initial application of pipe bursting in the FY-2007 project, HDPE pipe was specified because it was the primary type of pipe used at that time. As FPVCP became more used and accepted, BOPU began to specify it in their water rehab pipe bursting projects. In almost all new and rehab water distribution projects in which open cut installation was performed, PVC was the pipe of choice. Since contractors and in-house crews mostly worked with PVC, and because most appurtenances were PVC/DIP sized, FPVCP was the natural choice for pipe bursting projects.

4. EXISTING PROGRAM INCLUDING PIPE BURSTING

When specifying FPVCP and pipe bursting for water rehab projects, it is sometimes bid as an alternate to dig and replace with standard PVC pipe. Contractors are required to bid both options. Factors that determine if pipe bursting will be considered as an alternate include available space to string out fused sections of pipe, upsizing (if any) of the existing pipe, any excavation conflicts or difficulties, restoration requirements of open cut, and soil conditions of the trench. If existing pipes are being upsized, the potential volume displacement of soil during bursting must also be determined. In many cases, the unit rate cost for pipe bursting is higher than open cut, but the overall cost is lower because of the reduced restoration requirements such as subgrade restoration, road base, asphalt, and concrete replacement.

All of BOPU’s pipe bursting projects have utilized the static bursting process, as opposed to pneumatic bursting systems. In the static pipe bursting system, the bursting head expands the pipe only through the pulling action of the pulling tool. In a pneumatic bursting system, the bursting head has a hydraulic or pneumatic action.

The site is surveyed and soil borings are collected to determine the soil and ground water conditions. The existing pipe type, size, and location are also verified. Prior to any construction, all water services are located, uncovered, and transferred to a temporary water system. The first step in the construction process is to excavate access pits, and to remove any repair obstructions, valves, or other appurtenances. In pipe bursting, the older pipe is used as a conduit. After the bursting machine and fused pipe are set up, bursting rods are advanced through the old pipe and attached to a bursting head equipped with a cutting blade. The fused section of FPVCP is attached to the bursting head, and the fused pipe is pulled through the old host pipe with a hydraulically powered bursting or "pulling" unit. As the bladed bursting head is pulled through the old pipe, the blades split the old pipe and the bursting head fractures the pipe and forces the fragmented pipe into the surrounding soil. This creates a temporary annular space through which the new pipe is pulled. When the entire bursting operation is complete, the pipe is connected and tested. Water services are reconnected after all tests are passed, and all excavations are restored, much like dig and replace methodology.

As BOPU has performed more pipe bursting projects, the technical specifications have been modified and strengthened to reflect knowledge obtained through trial and error and advancing along the learning curve. In the most recent job, the FY-2012 rehab project, the following items were specified for the pipe bursting operations (some of the equipment manufacturers were the contractor’s choice):
• DR 14 C-900 DIPS FPVCP, supplied by Underground Solutions, Inc. (UGSI)
• Grundoburst 800G Static bursting tool manufactured by TT Technologies, with a rated pulling force of ~172,800 lbs.
• Static bursting head with wheel cutter
• McElroy fusion machine, adequately sized for required pipe diameter
• TensiTrak® pullback and pressure monitoring system
• Maximum pullback stress - 2800 psi
• Maintain continuous pulling force log
• Soloshot®Tracer wire by Copperhead Industries
• Fused pipe must be pulled on rollers, dragging along the ground is prohibited
• Video sewer services after the burst

5. CONSTRUCTION ADVANTAGES AND DISADVANTAGES

Overall, BOPU has been very pleased with the results of pipe bursting with FPVCP for the water rehab projects. Pipe bursting is one of the only no-dig options that result in an increase in pipe size and hydraulic capacity. Most other no-dig methods decrease the existing pipe inside diameter and hydraulic capacity. In many of the residential areas, the subgrade soils are in poor condition, and the restoration efforts of open cut would have added extra cost and difficulty to the job. This is in addition to the extra cost of asphalt and concrete restoration. Local residents in general are happier because of less overall construction disruption and continual access to driveways because there is no trenching. Several of the bursting jobs have occurred in park areas, and open cut activities would have resulted in significantly more damage than pipe bursting. Other advantages include a safer work area because of fewer excavations, the wide variety of pipe that is amenable to bursting, and the fact that even severely degraded pipe can be rehabbed as long as the bursting rods can be advanced through the pipe. Everything considered, pipe bursting has been a less disruptive option, with significantly lower restoration requirements.

Pipe bursting is not without its drawbacks, however. Many of the pulls that have been performed on BOPU rehab projects have been 400 feet or longer. Construction logistics usually dictate that all of the pipe be fused before bursting activities begin. Therefore, adequate space must be available to string out long sections of fused pipe. Fortunately, Cheyenne is not a densely built out city, and contains ample green and undeveloped areas (see Figure 3). To date, BOPU has been able to stockpile fused pipe without any problems. This may not always be the case in denser, more highly developed cities. In areas where stockpiling long sections of fused pipe is not possible, one option is to fuse shorter sections and then fuse the shorter sections together as the pipe is being burst. This is not as
productive as fusing the entire pipe at once into a single string, and may result in increased cost due to the decreased productivity.

Even though excavation requirements are reduced when using pipe bursting, there must still be excavation pits for each water service that needs to be reconnected. The result is a "checkerboard" patching on streets (see Figure 4). On the rehab projects, the service excavations are slurried with flowable fill because it is too difficult to compact the subgrade with traditional compacting equipment. There are emerging technologies that use robotics to reconnect water services, resulting in much smaller water service excavation pits. As these technologies become more commercially viable and available, this disadvantage will become less of an issue.

![Figure 4. Before (left picture, taken on 5th Ave.) and after (right picture, taken on Ocean Ave.) of pits on the street in terms of excavation required during project and final restoration. The orange barrels and plywood covers show the locations of service excavations, which are then backfilled and restored.](image)

Other disadvantages include a limit on the upsizing of the pipe, limits on the bend radius that can be pulled, ground heave that can occur with shallow pipes, and potential damage to adjacent pipes or utility lines caused by ground heaving. BOPU has experienced damage to deteriorated sewer services that were located next to the burst water main. As a result, one addition to the bursting specification is to video all sewer services after the burst.

Interestingly enough, one of the advantages of pipe bursting has caused negative reactions from some municipalities. Because pipe bursting is less intrusive, less asphalt and concrete repair is required. When utilities perform open cut operations, municipalities essentially get free street repair and repaving, as well as items such as curb and gutter, sidewalks, etc. The recent economic downturn has left many cities in a budget crunch, and they have looked for relief anywhere they can. By shifting some of the cost of these infrastructure repairs to utilities, tight budget dollars can be used elsewhere.

6. PULL FORCE INFORMATION

During the FY-2012 project, BOPU required the use of a pull force monitoring unit between the pull head of the pipe material and bursting head of the pipe bursting equipment. The goal for BOPU was to monitor the required pull force on the pipe to assure that the safe allowable maximum pull force values for the pipe sections being pulled were not exceeded during the installation. BOPU was looking for a way to verify the stress on the pipe section during the pipe bursting installation and found that a commercially marketed ‘load cell’ would do just that.
Figure 5. Longitudinal slots were cut in the expander head and then filled with epoxy. This allowed the TensiTrak unit to transmit from within the steel expander head.

The F5® TensiTrak pullback and pressure monitoring system, manufactured by Digital Control, Inc. (DCI®), is marketed to the horizontal directional drilling (HDD) industry for use during product pipe installation using HDD methodology. The unit is placed between the pulling equipment and the product pipe and it will measure the amount of force being applied to the pipe as it is being pulled into the borehole. The unit will also measure the annular pressure of the borehole as the installation is taking place, which can be advantageous in terms of limiting inadvertent fluid returns due to high pressures. For pipe bursting, the tensile force registration is the only applicable function of the unit since there is no annular fluid pressure to record. The TensiTrak tool also acts as a sonde unit, projecting an electromagnetic field which is received, monitored and recorded by a ‘walkover’ handheld receiver. This provides an estimate of the location of the unit in all three directions, as well as the actual and maximum tensile force data received to that point. All the data is stored on the receiver and can be accessed at a later time through software specific to the F5 unit.

Figure 6. Location of TensiTrak unit (the white and silver sub assembly shown in the picture on the left) under the expander head, between the pipe bursting equipment and pipe pull head.
The one modification required to use the unit with the pipe bursting equipment setup was to cut longitudinal slots in the expander head of the pipe bursting train, and then to fill them with epoxy (see Figure 5). This allowed the transmission of the unit to the receiver without being blocked by the expander head where the unit was placed (see Figure 6).

Aztec Construction of Cheyenne, Wyoming was the general contractor for the FY-2012 project. Levi’s Backhoe Service (Levi’s) of Douglas, Wyoming performed all of the pipe bursting for the project, which included 4 of the 5 rehab locations in Cheyenne. They also monitored all of the installations with the TensiTrak unit. During the installation sequence, they were able to monitor the effect of the pipe bursting activity on the required tensile force to pull the pipe into place in real time. This included any repair couplings or other difficult bursting locations, known and unknown during the installation. Pull force values witnessed and verified with the unit did not come close the allowable pull force capabilities of the pipe sections used, which was as expected, and was the primary goal of requiring the use of the equipment. As has been the conventional understanding for some time, the high pull force capability of FPVCP does not come into play on typical pipe bursting runs unless they are extremely long, or have very unusual circumstances associated with them.

Table 1. Specific details of a sampling of four locations where bursting was performed and nine total pulls from those four locations were recorded.

<table>
<thead>
<tr>
<th>Pull Location</th>
<th>Length (FT)</th>
<th>Alignment</th>
<th>Depth</th>
<th>Existing Pipe</th>
<th>New Pipe</th>
<th>New pipe String Weight</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lion’s Park – 2nd Pull</td>
<td>600</td>
<td>Large radius horizontal curve and flat</td>
<td>Not Recorded</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>6,620 lbs</td>
<td>These bursts occurred through a park area including botanical gardens, parking lots, etc. Area is flat, though some bursts took place along curvilinear alignments.</td>
</tr>
<tr>
<td>Lion’s Park – 3rd Pull</td>
<td>350</td>
<td>Straight and flat</td>
<td>Not Recorded</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>2,760 lbs</td>
<td></td>
</tr>
<tr>
<td>5th Ave. – West End</td>
<td>256</td>
<td>Straight and flat</td>
<td>6’-2” to 4’-10”</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>2,850 lbs</td>
<td></td>
</tr>
<tr>
<td>5th Ave. – Middle Section</td>
<td>295</td>
<td>Straight and flat</td>
<td>~4’-10”</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>3,250 lbs</td>
<td>5th Ave. is a straight street with a slight elevation rise at the east end of the length that was burst.</td>
</tr>
<tr>
<td>5th Ave. – East End</td>
<td>242</td>
<td>Straight with upward vertical slope</td>
<td>7’-4” to 4’-10”</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>2,670 lbs</td>
<td></td>
</tr>
<tr>
<td>Ocean Ave. – 2nd Pull</td>
<td>132</td>
<td>Slight horizontal curve and flat</td>
<td>Not Recorded</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>1,460 lbs</td>
<td>Ocean Ave. is a curvilinear street on which all of the pipe was burst. Not all data was gathered due to issues with the TensiTrak unit.</td>
</tr>
<tr>
<td>Ocean Ave. – 3rd Pull</td>
<td>350</td>
<td>Slight horizontal curve and flat</td>
<td>Not Recorded</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>3,860 lbs</td>
<td></td>
</tr>
<tr>
<td>Rio Verde – East</td>
<td>150</td>
<td>Horizontal curve and flat</td>
<td>8’ to 6’</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>3,300 lbs</td>
<td>The east end burst had a horizontal alignment curve and was flat; the rest of the street was straight and flat.</td>
</tr>
<tr>
<td>Rio Verde - West</td>
<td>180</td>
<td>Straight and flat</td>
<td>6’ to 5’</td>
<td>6” Cast</td>
<td>8” DR 14</td>
<td>1,990 lbs</td>
<td></td>
</tr>
</tbody>
</table>

UGSI worked with BOPU, Levi’s and the data that they recovered from the monitoring performed, not to verify the installations, but to evaluate the pull force data compared to the specific installations where they were recorded (see
information in Table 1). The goal was to see what the data may show in regards to pipe bursting in general and how it relates to tensile force applied to the product pipe. UGSI previously used the TensiTrak equipment from DCI to monitor the use of FPVCP in HDD installations with Arizona State University (Ariaratnam, 2010). This provided another opportunity to evaluate pull force data, albeit with a different installation methodology.

The at-grade pulling force was evaluated, which is the force that is recorded moving the pipe string into the insertion pit prior to the bursting process beginning. Though other forces are at play for insertion into a pit and the beginning of the installation, initial pull forces were compared to dead weight and modeled as an approximate “friction factor.” Across the nine installations, this approximated friction factor ranged from 0.04 to 0.37. The large differences tended to be in the longer insertion lengths as well as those that needed to follow a curvilinear pathway around a corner or other obstacle to make it to the insertion location, causing a higher relative friction value. These values fall well within the 0.1 to 0.5 range that is consistent with other data gathered for at-grade based pipe movement into tensile based insertion scenarios.

Installation of the pipe occurs as the equipment cycles through ‘pulling’ and ‘rest’ or ‘hold’ actions. The higher forces associated with pulling the pipe as well as the lower forces realized whenever the pipe and equipment was at rest of on hold were evaluated. The trend lines of these two data sets for each installation are basically linear in nature. However, there can be large variability around these trend lines in terms of the actual peak data recorded. It is important to note that the TensiTrak unit records data every 2 or 3 seconds, therefore, the high peak force or the low rest force realized may not be recorded exactly due to the cyclical, short duration loading that is applied during the pipe bursting process. The unit does record the maximum force regardless of when it happens or regardless of if it occurs during a data point acquisition point however. This understanding was reflected on almost every installation recorded, as the max force, usually a very quick tensile impact load after going through a repair clamp or particular cast iron bell joint, was realized at a time when the data point was not being acquired.

Trend lines for the higher pulling forces associated with the pulling cycles generally were steeper and much larger in magnitude than that of the residual values when the cycles were at rest. Additive pounds per linear foot (lbs/LF) of installed pipe ranged from 1 lbs/LF to 13 lbs/LF for these active forces. Additive force for the rest cycles tended to be flat or shallower in slope, ranging from near 0 lbs/LF to 6 lbs/LF. These value ranges could be due to several factors, including varying contributions from the frictional component of the at-grade pulling forces, the variation in horizontal alignments including known curved sections, and possible variations in soils and buried environments. See Figure 7 for a plot of this data specific to an Ocean Ave. insertion and sample trend lines derived from the data.

![Figure 7](image_url)

Figure 7. Example plot of trendlines and pull force data for the second installation on Ocean Ave.

It was noted that one of the 5th Avenue insertions exhibited high growth in the first half of the installation (~11 lbs/LF) and then actual decay (~1.3 lbs/LF) in the second half of the installation, meaning that it took progressively
less force to pull the pipe as the insertion progressed past a certain point. This installation was the only one to show this type of reduction in pulling load as the installation proceeded.

The maximum force values for all pulls were at 8,200 lbs or less, but all of these values were the short term, quick “pull-through-an-obstruction” type of loading. They were not sustained and the data points to the fact that only a fraction of this realized force remained in the pipe during rest periods, even immediately after the peak event timing. Longer term trending of loading on the pipeline is more likely to be the critical parameter for the pipe and long term residual stress in the pipeline, as long as the peak installation loading is below the safe allowable pull force for the pipe section. In this regard, from the data evaluated, values ranged from 1,300 to 4,500 lbs. This represents an axial stress on the pipeline of approximately 270 psi (for 4,500 lbs). The highest, short duration, peak force ever recorded on the pipe from this data was ~8,200 lbs, which represents ~480 psi axial stress. Safe allowable pull force values are based on a stress of 2,800 psi.

7. RESULTS OF THE PROGRAM

The City of Cheyenne and the Board of Public Utilities are much like any mid-sized utility in the country, they struggle with water sourcing, adequate supply and aging infrastructure. Experimenting with various rehabilitation methods has been worthwhile for the BOPU, resulting in the increased use of pipe bursting as a means to rehabilitate their water distribution system. The current program has been a success, replacing aged and undersized infrastructure at a minimum impact to residents and rate payers, while costing less than conventional dig and replace methods.

The current program has also yielded some interesting data in terms of pipe bursting in general – data that may further the general understanding of pipe bursting and the way that the replacement pipe interacts with the ‘burst environment’ during the installation. The data gained thus far has put brackets around the stress that the pipe sees for Cheyenne-based parameters. It reveals that there can be a wide variation in forces realized in similar applications, with a general upper limit that is well within the replacement pipeline material capabilities. Pull forces seem to be influenced by and trend according to pipeline alignment, layout room, depth of bury, soil conditions, and length. It also shows that there is only a fraction of the residual stress from the installation loading that stays with the pipe after installation is complete. It is critical to note that while this was a general trend for these monitored installations, this cannot be assumed for all installations. Several of the insertions monitored included larger residual stress concentrations.

8. REFERENCES