REHABILITATION OF UNDERGROUND INFRASTRUCTURE UTILIZING TRENCHLESS PIPE REPLACEMENT

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ABSTRACT: Trenchless pipe replacement, or pipe bursting, is a construction method that provides an alternative for rehabilitating underground infrastructure with minimal disruption to surface traffic. It is recognized as the only method of trenchless pipe rehabilitation in which a buried pipe can be replaced with a completely new pipe that functions independently of the existing line and permits the diameter of the new line to be increased. This paper presents an overview of three bursting systems currently used in the North American industry with discussion on the anatomy of a pipe bursting project, sequencing, risks, and a comparison of project elements to traditional open trench methods of construction. This paper concludes with three case studies describing the application of pipe bursting on projects that extended the current operating envelope of the technology to illustrate project specific engineered solutions to particular rehabilitation requirements. Through the sharing of knowledge and experience, a greater understanding of the technology and its application may be achieved to promote trenchless pipe replacement as a viable alternative to open cut construction methods.

INTRODUCTION

Traditional methods of underground pipe rehabilitation or replacement have typically encompassed the use of open cut or lining methods of construction. The replacement of pipe using conventional cut and cover techniques can have adverse impacts on the daily life and activities of the people and businesses around the rehabilitation project. Typically, road closures, traffic delays and redirections, loss of access to businesses and homes, as well as undesirable noise and sight pollution are common with open cut type projects. If lining techniques are employed to rehabilitate buried infrastructure, there is generally a slight reduction in the diameter of the original line, which typically reduces the total capacity of flow. Subsequently, if a line was at or near capacity, the only method previously available to increase the capacity of the line has been open cut replacement. With increased urbanization, underground congestion has increased, making it more costly, if not impossible in some situations, to employ traditional open cut construction techniques. For these reasons, it became apparent that a new perspective on rehabilitation (i.e., trenchless pipe replacement) was necessary to alleviate some of the shortcomings of traditional construction methods.

Trenchless pipe replacement is a relatively new technology that has only been applied to the rehabilitation industry in North America, over the past 10 years. Developed approximately 20 years ago, the technology has been utilized extensively and successfully through parts of Europe. Since coming to North America, the technology has increasingly been recognized as a viable and practical alternative to open cut and lining methods of buried pipe rehabilitation [International Society for Trenchless Technology (ISTT) 1999]. It is recognized as the only method of trenchless pipe rehabilitation in which a buried pipe can be replaced with a completely new pipe that functions independently of the existing line and permits the diameter of the new line to be increased, in some cases, to over 300% of the original.

This paper is intended to provide the designer with a background on trenchless pipe replacement and highlight its capabilities and applications in the underground infrastructure rehabilitation industry. An introduction to trenchless pipe replacement techniques is provided to explain the technology and the various methods utilized in the industry. The paper describes rehabilitation techniques for the replacement lines using both sectional and continuous new pipe materials, followed by a discussion of techniques utilized in the replacement of service laterals. As trenchless pipe replacement is an emerging technique, a discussion of project planning considerations, as related to project geometry, and a section on technology specific risks are presented to provide the designer with general concepts in how planning and risk differ from other methods of rehabilitation or replacement. To provide a clearer understanding of rehabilitation methodologies, a comparison and practice guideline to the selection of an appropriate rehabilitation process as related to infrastructure requirements is briefly discussed. This paper concludes with three case studies describing the application of pipe bursting on projects that extended the current operating envelope of technology to illustrate project specific engineered solutions to particular rehabilitation requirements. Through the sharing of knowledge and experience, a greater understanding of the technology and its application may be achieved to promote trenchless pipe re-

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placement as a viable alternative to open cut construction methods.

TRENCHLESS PIPE REPLACEMENT

Trenchless pipe replacement, or pipe bursting, is defined as the replacement of the host, or original, pipe by fragmenting the existing conduit and installing the product or new pipe in its place [Committee on Construction Equipment and Techniques (CCET) 1991]. Pipe bursting is recognized as the only method of trenchless rehabilitation that can replace an existing line with a completely new pipe, thus providing a total pipe replacement. Additionally, pipe bursting allows for the replacement of existing pipe with a new line of equal or larger diameter, to maintain or increase flow capabilities. These are two distinct capabilities unique to pipe bursting in comparison to other rehabilitation methods in the trenchless arena.

In general, pipe bursting is accomplished by the advancement of a cone-shaped bursting head through an original pipe that due to its geometry translates forward thrust into radial expansion forces. These radial expansion forces overcome the original pipe's tensional and shear strength capabilities and subsequently bursts or splits the pipe. Attached to the rear of the bursting head is the new line, which is simultaneously installed as the bursting head advances and bursts the pipe. This technique has been used to replace cast iron, clay, reinforced concrete, polyvinyl chloride (PVC), high-density polyethylene (HDPE), and ductile iron pipes. Typically, HDPE pipe is the material of choice as the replacement line, though clay, concrete, PVC, and steel pipe can also be used for either continuous or sectional installations (Ariaratnam et al. 1999).

One of the principal advantages that pipe bursting has over conventional methods of pipeline replacement is the minimal amount of excavation required to replace existing lines. Typical replacement pipe sizes range from 50 to 400 mm in diameter, and lengths between 100 and 200 m. Diameters up to 910 mm have been accomplished in St. Petersburg, Fla. (Thomas 1996) and lengths up to 470 m in Stockbridge, Mass. (Saccogna 1997). Upsizes are typically on the order of 30%, though upsizing up to 320% of the original pipe size has been accomplished (Fraser et al. 1992).

PIPE BURSTING SYSTEMS

There are three main bursting systems currently used in the North American pipe bursting industry. These include the static, pneumatic, and hydraulic expansion systems. The main difference between each method is the manner in which force is generated and transferred to the original pipe during the bursting operation. A schematic illustrating the differences between these methods is presented in Fig. 1.

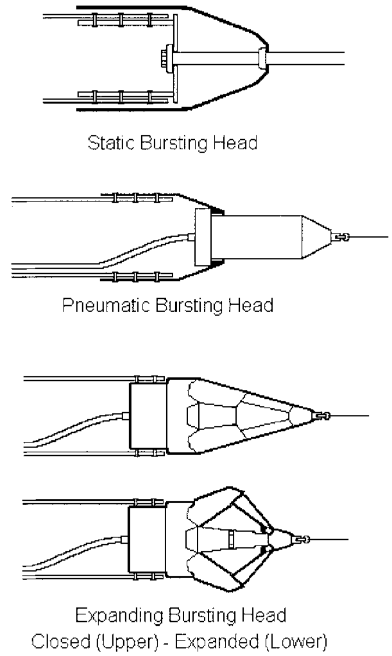

FIG. 1. Bursting Head Configurations

Static Method

Static methods burst the original pipe using static forces, or forces developed from the geometry of the bursting head as it is pulled or pushed through the existing pipe. A pulling force is applied to the cone-shaped bursting head through rods, cable, or chain. The bursting head then is pulled through the pipe causing the existing inground pipe to fail in tension by the radial force applied to the pipe wall from the cone within the pipe. As the host pipe is burst, the bursting head pushes the broken pipe pieces into the soil as it displaces the surrounding soil, thus creating a cavity for the new product pipe. A static bursting head that utilizes rods to pull the bursting head through the original pipe is illustrated in Fig. 1.

The majority of static pipe busting equipment is modeled after high-powered hydraulic jacks, mounted horizontally rather than vertically. The smaller units usually use two hydraulic cylinders to develop the required pulling force, while the larger units usually use four or more. Mounted in the center of the pistons is a mechanism to grab the chain or rod during the pulling operation. As the machine pulls the rod or chain, it is disconnected, and the gripping assembly moves forward to grab another section of rod or link of chain. This process is repeated until the installation is complete. If a cable is used, it is usually pulled by a winch that is located in the machine or pulling pit.

Pneumatic Method

The pneumatic pipe bursting method utilizes a bursting head that displaces the soil using a horizontal hammering force developed with air from a compressed air system. Using compressed air, the bursting head is able to develop a hammering rate of 180–580 blows/min (TT Technologies 1997). The cone-shaped bursting head is driven through the soil like a nail being driven into a wall. Each blow impacted by the bursting head into the pipe creates an impact load, applying a ''hoop'' stress into the pipe causing it to burst in tension. In addition, the hammering action creates force in the longitudinal orientation, causing failure in shear as the pipe is ripped. The shape of the head, combined with the percussive action push the pipe fragments into the soil, providing the space necessary for the installation of the product pipe.

With this method of pipe bursting, the bursting head is guided through the pipe with the use of a tensional cable inserted through the pipe prior to bursting. This cable is attached to the bursting head and provides constant pulling tension, through the use of a winch, to keep the bursting head in contact with the host pipe and aligned with its path, as well as assist in pulling the new host pipe into place. The main force that allows the progression of the bursting head through the pipe comes from the percussive hammering action of the pneumatic head itself. Both the air compressor and the winch are set at constant pressure and tension that allow the operation to proceed with little operator intervention until the pipe section is burst. To power the bursting head, compressed air lines (hoses) must be run through the new product pipe.

Hydraulic Expansion Method

This method of pipe bursting is defined by the method in which the host pipe is burst. Rather than the pipe being burst from the transfer of an axial pulling or hammering force radial into the plane of the pipe diameter, the bursting head expands radially fragmenting the pipe from inside. Using hydraulic cylinders, the head expands to burst the pipe, then contracts to allow the winch to pull the cable and advance the head incrementally forward. The winch or pull on the cable does not assist in the bursting of the pipe, but rather pulls the head to help displace any residual soil formation as well as pull the product pipe into the expanded cavity.

Similar to the pneumatic pipe bursting system, the hydraulically expanding bursting head requires a power source to provide energy to burst the pipe. In this case, a portable power unit at the machine pit, on the surface, provides power for the hydraulic cylinders, with hydraulic hoses run inside the entire length of the product pipe.

ANATOMY OF PIPE BURSTING PROJECT

In general, the pipe bursting project is subdivided into sections or lengths that the specific equipment being used can burst based on the geometry and layout of the total length of pipe being replaced. The length of pipe that can be replaced in a section is dependent on the type of pipe being burst, degree of upsize, soil conditions, geometry of the original installation, and the type of bursting equipment and method used. In addition, the new pipe, whether it is continuous or sectional, will dictate the type of equipment required and the pit setup. This section describes the application of static pipe bursting techniques for the rehabilitation of distribution and collector lines for the installation of both sectional and continuous pipe. The section concludes with a description of a lateral or service rehabilitation using the static pipe bursting process.

For the installation of continuous pipe, such as HDPE or steel, access pits must be excavated at each end of the pipeline to be replaced. On one end of the line, the machine pit is excavated into which the pipe bursting machine that pulls or directs the bursting head is located. Opposite the machine pit is the insertion pit through which the new pipe or product pipe and bursting head are inserted into the existing or host pipe. The setup for a typical burst using static pipe bursting is shown in Fig. 2. In this case, the pulling mechanism could consist of rods, chain, or cable. Any services along the pipe route connected to the original pipe must be disconnected prior to the start of the burst with access to the connections achieved through service pits.

A slightly different setup is required if sectional nonwelded joint (clay, PVC, or reinforced concrete) pipe is used to replace the existing line. Again, access pits are excavated at each end of the line to be replaced, except in this case both pits are considered machine pits. The installation of sectional pipe requires that constant force be applied to the pipe to keep the joints together during installation. This may be achieved by using a chain or cable run through the new line from the bursting head to a trailing plate on the last pipe section, or alternatively by using a push-pull technique. In the push-pull setup, the bursting head would be pulled by one machine in the pulling pit, while in the opposite pit, the pipe section would be pushed by another machine as illustrated in Fig. 3. In this setup, a constant pressure is applied to the new pipe during installation by maintaining the push force slightly higher than the pulling force. This requires the synchronization of the two machine forces, but allows for large

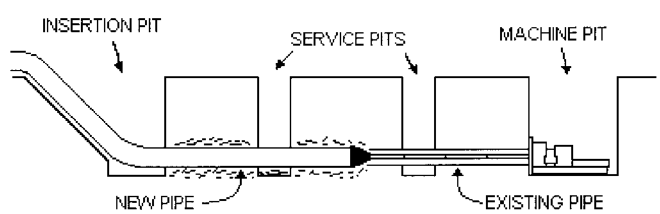

FIG. 2. Typical Configuration for Continuous Pipe Installation

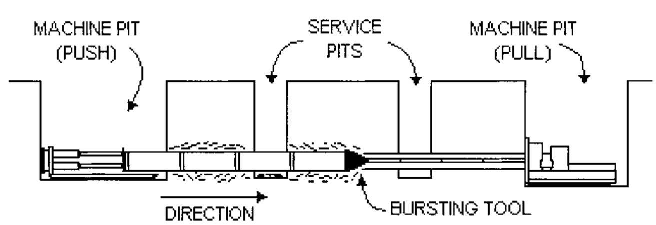

FIG. 3. Typical Configuration for Sectional Pipe Installation

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diameter installations to be achieved. One such installation occurred in St. Petersburg, Fla., where 230 m (770 ft) of 900 mm (36 in.) diameter vitrified clay pipe (VCP) was successfully replaced with 900-mm-diameter Hobas pipe (Thomas 1996).

The size of the machine pit depends on the size and type of pipe bursting equipment used. Machine pits used in static pipe bursting can range in size from 4,050 × 2,500 mm (13.3 × 8.2 ft) to the size of a manhole. Some types of bursting equipment only require the installation of a cantilever structural arm with redirecting sheaves into a manhole to direct and pull a wire rope cable or chain.

Insertion pits are generally smaller than the machine pits. Typically, for static bursting methods using continuous pipe, the length of the insertion pit should be 12 times the diameter of the new product pipe plus a length to account for the slope depending on the depth of the excavation at a ratio of 1.5–2.5 run to 1 depth [Trenchless Replacement Services Ltd. (TRS) 1997]. The slope ratio largely depends on the bend radius of the product pipe. The width of the insertion pit need only be 1,200 mm (4 ft) (TRS 1997).

If sectional pipe is used as the replacement pipe, the length of one section of pipe will determine the pit length, with allowance for worker, equipment, and shoring space to aid in the placement of the pipe. Width, similar to the length, depends more on the space required for the handling of the pipe during the lowering of the pipe.

Service pits may be excavated with a minimal surface footprint. The size of pit depends on the depth of excavation and the capability and maneuverability of the excavation equipment in the confined space of the pit. Generally, a service pit only needs to be 1,200 mm (4 ft) in diameter to provide sufficient space for a worker to disconnect and reconnect the lateral. These pits may be shored using either large diameter steel pipe sections or trench shoring, depending on the pit dimensions and depth.

In older and established neighborhoods, the replacement of buried infrastructure can cause considerable disruption. This is especially the case when the laterals or services to individual businesses or residences need replacement. In this situation, there may be considerable disturbance to valuable landscaping and inconveniences due to the lack of access to a property with conventional cut and cover replacement options. Pipe bursting offers a unique solution to the replacement of service laterals that allows for minimal disruption to the property under consideration.

To facilitate the replacement of the defective lateral, it must first be disconnected from the main line, and preparations made to improve access to the location where the lateral enters the property (Fig. 4). In the case of a residential structure, a small area of the concrete floor around the lateral must be removed to increase the available space for pulling the new product line into the existing one. Most lateral replacements are conducted using a cable or chain pulling system as this allows the greatest flexibility for the limited space available. The new pipe lateral is typically of a continuous nature that is inserted from the basement of the residence as illustrated in Fig. 4. Since a cable or chain is used in this installation, a pulling unit equipped with a winch system is used to advance the bursting head through the host line.

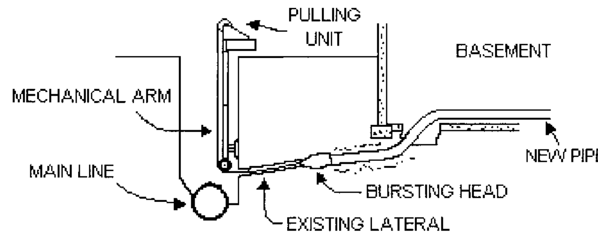

FIG. 4. Lateral Replacement Pipe Bursting

A pulley attached to the end of a mechanical arm is used to direct the cable to the surface where a winch pulls the bursting head through the pipe. After installation is complete, the line is relaxed to reduce any residual strains from installation prior to reconnection to the main line. Restoration of the site and basement can then be performed. In general, lateral replacements conducted in this manner can be completed in less time and with less disruption to the owner than open cut methods.

BURST SEQUENCING

In the planning of a trenchless replacement project, consideration must be given to the arrangement of the pulling machine and pipe insertion pits, since the most time-consuming operation in the pipe bursting process is the setup of the machine and the excavation of pits. Therefore, the number of setups and amount of excavation should be minimized. Prior to mobilization, the planner must consider the arrangement of pipe sections and manholes. It is best to plan multiple uses for machine pits to minimize equipment transportation and relocation, as well as the number of times the power plant is required to be setup. If a section of pipe that is being burst is a continuation or is in line with another section of pipe joined with a manhole, that manhole would best serve as a machine pit. With this arrangement, after the first section of pipe is burst, rather than the rods or chain being disconnected as they are pulled, the rods can be shunted (or chain pulled) down through the next section of pipe to be burst. This increases the productivity of the operation by shunting rods (or chains) down one section of pipe while simultaneously bursting another.

In selecting the arrangement of the pits, there are a few practices that a planner may use. The first is that machine pits should be located at intersections of pipe segments where the segments are oriented in the same direction, or a continuation of the pipe segments. This allows the pit to be used twice by pushing rods down the next pipe segment to be burst, while bursting the first. The second, as dictated by the first, is that insertion pits are best located where there is a change in the alignment of consecutive pipe segments (i.e., bends in the line). Both of these rules contribute to minimizing the number of equipment and plant setups.

For example, to increase productivity, Fig. 5 shows that if the line between two manholes (MH 93 and MH 98) was replaced by pipe bursting, pits should be located such that they could be used more than once during the burst. For this scenario, the line is considered to be a concrete gravity storm sewer, flowing from west to east. During the installation of the line, it is best to pull the pipe down the grade to keep the proper grade when complete. Optimal setup of this project would have MH 98 as an insertion pit, MH 97 as a larger machine and insertion pit, MH 96 as a machine pit, MH 95 as an insertion pit, MH 94 as a machine pit, and MH 93 as an insertion pit. Using this setup, the machine only needs to be transported and set up three times, while minimizing the total pit excavation volume.

The installation would begin by inserting the new pipe at MH 98 and pulling the pipe through to MH 97. MH 97 would be used as a machine pit for the first section and then as an insertion pit to install the second section. Next, the pipe bursting equipment would be transferred to MH 96, where it would pull the pipe in through the insertion pit at MH 97, while simultaneously shunting rods to MH 95. This is done so that the machine can be repositioned in the pit ready to pull rods as soon as the bursting head and product line are attached to the drive string at MH 95.

In continuing the installation, the machine would be moved to an excavation at MH 94, and pipe would be pulled from MH 95 and then MH 93; this would complete the installation. In this situation, rods could not be shunted through the section between NH 94 and MH 93 due to the change in alignment of the line. Alternatively, if a chain or a cable was used, it could be pulled to MH 93 to facilitate the insertion of pipe. Using this setup procedure the total installation time can be reduced by minimizing equipment setup time.

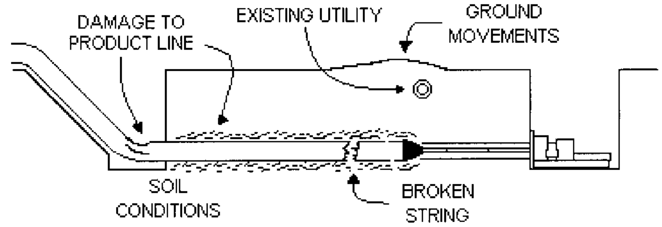

FIG. 6. Risks Associated with Pipe Bursting

PROJECT RISKS

The effective handling and controlling of risk is essential to the successful and safe completion of any construction project. Since trenchless construction projects require some degree of excavation and work below the ground surface, they essentially have many of the same risks associated with more conventional open cut installation procedures. Additionally, pipe bursting projects have risks that are specific to the bursting process that must also be considered (Fig. 6).

Damage to New Product Line

During the installation of the new product line, one must be aware of the properties of the pipe that is being

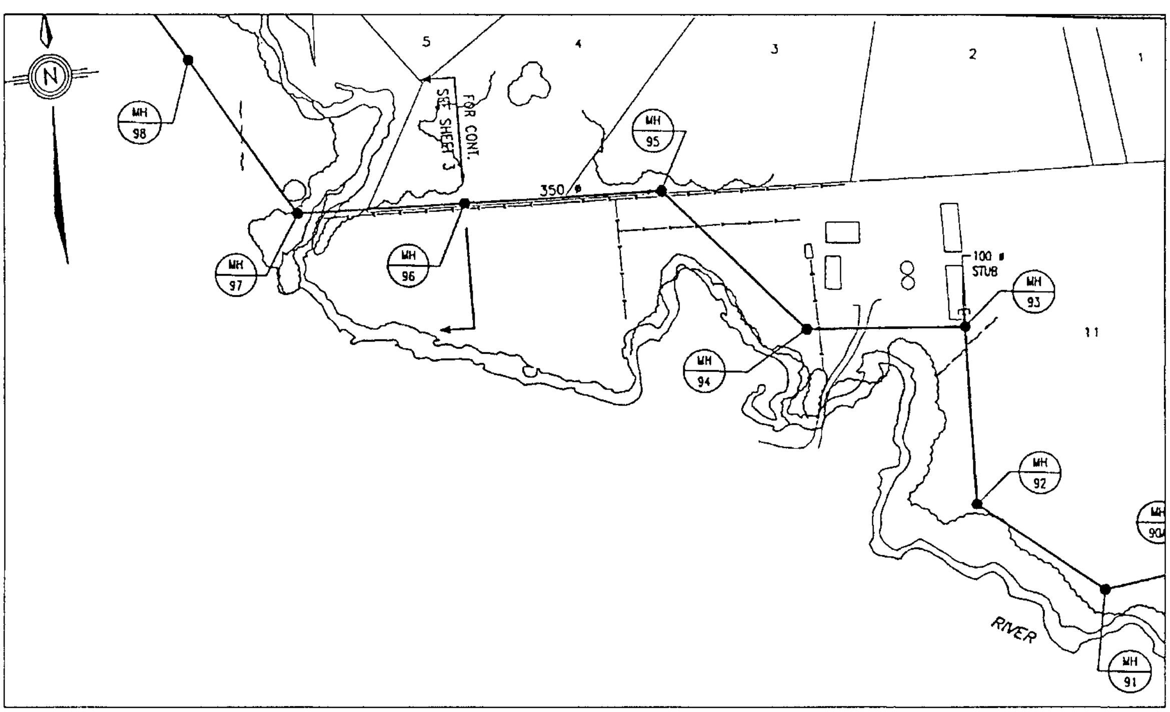

FIG. 5. Example Pipe Bursting Project

installed. It is essential that bend radius specifications for continuous pipe, in particular for HDPE pipe, be followed such that localized pipe buckling or collapse does not occur as the product sting is pulled into the insertion pit during installation. If this occurs, it would be necessary to stop the installation and repair of those sections that have experienced localized failures. Additionally, these localized deformations may weaken the integrity of the pipe and, subsequently, contribute to the product line failing in tension during the installation.

As the original pipe is burst and the cavity expanded for the installation of a new product line, the fragments and remainder of the original pipe remain in the soil. These fragments are in direct contact with the wall of the product line as it is pulled through the ground. This presents the possibility of damage occurring is the surface of the new host pipe. The pipe materials most susceptible to this type of damage are HDPE and PVC pipes. Subsequently, cast iron and concrete pipes are most likely to initiate this type of damage due to the nature of their fragmentation. Although not formally published, interviews with several contractors and manufacturers indicate that most surface damage does not penetrate more than 10% of the wall thickness of the new product pipe. Therefore, to mitigate the risk of reducing the pipe wall thickness during installation, the best solution would be to increase the specified wall thickness on pulls in which cast iron or concrete pipes are burst.

Breaking of Product Line

One of the most undesirable events that may occur during installation is failure of the new product pipe. This typically occurs when the pull force required for installation exceeds the tensile strength of the pipe. In general, failures of this type occur where localized damage has occurred from improper handling of the pipe. Additional friction on the pipe from the soil may increase the likelihood of this type of failure occurring. When the product string breaks, the only remedial actions are either to excavate to the location where the broken pipe is suspected and continue the installation using conventional open cut methods or alternatively pull the remainder of the product line out of the cavity and restart the installation.

Ground Movements

Perhaps the greatest impediment in the adoption of pipe bursting to main line pipe replacement is the uncertainty associated with ground movements. Regardless of whether the original pipe is replaced size for size, or with a larger pipe, the ground around the original pipe cavity will ultimately move. Therefore, care must be exercised whenever bursting in close proximity to buried utilities and conduits. Ground movements may also occur on the surface if the depth of cover above the pipe being burst is too shallow. The minimum depth of cover is dependent on soil conditions, installation geometry, size of host pipe, and degree of upsize. The vertical ground movement will manifest itself as surface heave. Depending on the nature of the cover material, this surface heave may cause permanent damage to pavements or foundations above the bursting operation (Ariaratnam et al. 1999). Therefore, it may be prudent to monitor existing structures, utilities, and pavement during installation.

With proper locating and identification of the utility rights-of-way around the host pipe and preconstruction surveys along the right-of-way, measures can be taken to reduce the effects of the ground movements on these utilities. To reduce the effects of surface heave, it may be possible to place additional load on the surface in areas of concern while the burst is conducted. The additional weight on the surface may assist in redistributing the ground displacement more in a lateral direction, therefore reducing the surface heave.

Soil Conditions

Another factor that can affect the pipe bursting operation is the nature of the subsurface soils. In general, soils that are best suited for open cut excavation are also well suited for pipe bursting. Problems may occur when bursting in dry granular soils such as sand. In particular, as the burst progresses, vibration from the operation can assist in the compaction and constriction of the sand around the product line. This redistribution of the sand may increase the friction caused by the soil, therefore increasing the force required to pull the new product line in place. Regardless of the type of soil around the pipe, the amount of force required to pull the product line increases with the length of installation. Subsequently, if the sand has constricted around the pipe, as the length of pull increases, the force necessary to complete the pull may exceed the pull or push capabilities of the pipe bursting equipment being used on the project. This emphasizes the importance of proper site investigation to determine the composition of the soil around the existing pipe and consequently to ensure that properly selected equipment is used to complete the installation.

COMPARISON OF TRENCHLESS AND TRENCHING METHODS

In comparison to conventional open cut techniques of pipe replacement, pipe bursting has several inherent advantages. From experience, it has been shown that in almost all circumstances, pipe bursting has cost less than open cut alternatives, completed the installation in less time, and, as a result, been a more efficient construction method. The main advanatage pipe bursting has over open cut methods is that, in pipe bursting, a minimal amount of excavation is required. This especially comes into play when one compares the cost of open cut excavation to that of pipe bursting. As the depth of installation increases, the cost of installation using pipe bursting almost remains constant. In comparison, the cost of open cut excavation

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increases greatly as the depth of the installation increases. This is largely due to the increased need for dewatering, shoring, and extra excavation often required during open excavation operations (Poole et al. 1985).

There are also social costs to consider when one compares pipe bursting to open cut excavation. Social costs include the intangibles that one cannot accurately quantify using financial terms. These costs include the loss of access to a driveway or garage, or the closing of sidewalks and parking areas in a downtown business district. This is where pipe bursting has a distinct advantage over open cut, especially in urban centers or nongreen field applications (McKim 1997). To replace a line using open cut methods, the entire line must be excavated where, with pipe bursting, only a machine pit and insertion pit need to be excavated. This minimizes the interference with street traffic, reduces noise pollution, reduces environmental disturbance, and reduces ground settlement, as there is minimal pore pressure reduction in the soil strata. A typical pipe bursting replacement can be performed using only a one-lane right-of-way, thereby maintaining the flow of traffic on the road. These are significant reasons why trenchless pipe replacement is more advantageous to implement than conventional open cut techniques.

In general, the selection of pipe bursting as the replacement option can be attributable to situations where restoration costs are high, such as beneath roads or highly landscaped areas, or in areas of high underground utility congestion. Additionally, if the authorities prohibit the use of open cut methods in environmentally sensitive areas, or in locations of high traffic, pipe bursting becomes a favorable replacement method. Perhaps the situation where pipe bursting becomes the most viable, if not the only option for replacement, would be when the pipeline right-of-way is inaccessible due to existing structures or obstructions and utilities. These situations make the utilization of pipe bursting more feasible than conventional cut and cover options.

The main contrasts between trenchless and open cut projects are presented in Table 1. The table compares several planning elements that are common for the rehabilitation or installation of subsurface utilities. This illustrates many of the advantages that trenchless construction has over more conventional open cut methods that have been used for pipe installation and rehabilitation. In most cases, due to the reduction of excavation and spoil handling, site restoration, and speed of the operation, pipe bursting methods can complete the rehabilitation of pipes in a shorter time and with reduced social costs than traditional open cut methods (TRS 1997). The issue of traffic control is of great concern when working in areas of high vehicular and pedestrian usage. In many situations, the closing of a route or street due to construction activities causes disruption to the businesses and residences in and around the closed road. Loss of access for customers, increased traffic due to detours, and noise are the effects of construction activities. Through the utilization of trenchless construction methods, many of these problems can be minimized or eliminated. One of the main advantages of pipe bursting in the replacement of pipes beneath roads is that only one lane is required to situate the equipment necessary to perform the replacement. Subsequently, traffic flows can be maintained along the site in question, minimizing the impact on the surrounding area.

TABLE 1. Comparison of Project Elements for Trenchless and Nontrenchless Projects

Planning element (1)	Trenchless construction (2)	Conventional open cut (3)
Safety	Only pits required	Trenches required
Excavation	Depending on method—minimal or none required	Entire length of installation must be exposed
Traffic control	Minimal—if any	Usually required
Utility support	Typically not required	Often required
Site restoration	Depending on method—minimal or none required	Major resurfacing or restoration required
Worker experience	New technology—limited pool of skilled workers	Proven method—many skilled workers
Schedule	Hours/day	Days/weeks
Cost (Poole et al. 1985)	Economical when depths exceed 3 m	Economical at depths shallower than 3 m

Most trenchless pipe replacement techniques generally require some amount of excavation to be performed to complete the installation. The amount of excavation required on a pipe bursting project is substantially less than that required on an open cut project for the replacement of the same pipe or conduit. This translates into reduced risk due to minimizing the time required for crews to work in excavations, as well as minimizing the ground disruption around buried utilities and building foundations.

In comparison to other trenchless methods, the decision to use pipe bursting over another rehabilitation or new construction method is determined by the present and future needs of the infrastructure system. In situations where the volumetric capacity of the line needs to be increased, pipe bursting provides the only trenchless alternative (Ariaratnam et al. 1999). In comparison to conventional lining methods, where the original pipe must be structurally sound to provide an effective rehabilitation, pipe bursting provides a complete structural replacement independent of the original condition of the line. Additionally, if a new line or grade is required, pipe bursting is incapable of changing these conditions; therefore, directional drilling, auger boring, microtunneling, or pipe jacking would be better trenchless alternatives. Lastly, consideration must be given as to whether the existing pipe requires a complete replacement, complete or partial lining, or only spot repairs to fulfill the existing and future service requirements. These considerations will determine how pipe bursting compares to other trenchless rehabilitation and new construction methods for a particular application.

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LESSONS LEARNED IN TRENCHLESS PIPE REPLACEMENT

Much may be learned from a project that is completed successfully and on time; however, one can learn more from projects where difficulties were encountered and new or innovative solutions had to be found to facilitate the completion of the project. The following section presents three case studies in which various difficulties were encountered during the application of trenchless pipe replacement. In each study, a brief introduction to the project is presented, followed by difficulties encountered in the replacement procedure, and the ultimate solution reached to facilitate successful completion. In all situations, the method that overcame the difficulty provided valuable information that has been incorporated into the repertoire of methods to replace pipe by the pipe bursting method.

Case Study No. 1: Size for Size Replacement of 450-mm-Diameter Corrugated Steel Culvert

Background

Pipe bursting has been used to burst a variety of pipes with success, though some types of pipe material are very difficult to burst due to their inherent material properties. In particular, corrugated metal pipe (CMP), or culvert, has been difficult to burst due to its structural composition. During bursting of CMP, it tends to stretch and, rather than burst or split, compresses in an accordionlike manner often creating a very densely packed and thick walled pipe mass. Additionally, the method in which sections of CMP are joined typically doubles the pipe wall thickness, and, with some joints, a much heavier tension band or hoop constricts the joint to maintain the joint integrity. These clamps or hoops on the joints are designed to resist much higher hoop tensile forces than the rest of the pipe. As a result, most bursting methods experience difficulty bursting corrugated metal pipe.

In September of 1996, Debco Construction Inc. was awarded a project in the city of Renton, Wash., to burst CMP. The project consisted of the replacement of approximately 300 m of 450-mm-diameter storm sewer line at a depth of 3–4 m in wet blue clay. The CMP was to be replaced with 450-mm-diameter HDPE pipe. Due to the geometry of the project and the difficulty of the burst, the project was subdivided and burst in three sections approximately 100 m in length.

Difficulties and Solutions

From previous experience, Debco knew that, in order to successfully burst CMP, one had to ensure that the existing pipe split or tore to prevent the existing pipe from constricting around the new pipe during the burst. Additionally, it was imperative to prevent the pipe from being pulled along with the bursting head as this contributed to the pipe collapsing closer to the bursting equipment in the machine pit. With the soil conditions on this project being wet clay with considerable amounts of silt, preventing the corrugated pipe from sliding and being pulled along with the bursting head was a major concern. To successfully burst the pipe, it would need to be initially cut or split prior to expanding the cavity for the installation of the product line.

On previous bursts involving CMP, Debco made modifications to the bursting process in an attempt to successfully burst the pipe. This included adding cutting fins to assist in splitting the pipe ahead of the bursting head. Debco, using a static bursting method with the bursting head pulled by rods, added cutting fins to a rod section approximately 1 m ahead of the bursting head. The cutting fins spread out from the rod with an ultimate diameter greater than the diameter of pipe being burst. This method worked well initially; however, as the burst progressed, the fins ceased cutting and began to elongate the pipe along the axis of the cutting fins making the burst more difficult. Therefore, when presented with a similar situation on the project in Renton, a new solution was found.

To solve the problem, Debco developed a new process that used cutting wheels rather than fins. Using a 1-m length of steel pipe with a diameter slightly less than the inside diameter of the CMP, cutting wheels were attached to the pipe wall to create a new cutting tool. The cutting tool was run approximately 1 m in front of the bursting head to cut the pipe and enable the bursting head to displace the pipe and soil while installing the new pipe. The cutting wheels were approximately 150 mm in diameter and composed of a tough cutting grade steel to resist wear. By having the cutting wheels rotate while cutting, the potential problem of the pipe collapsing and being pulled along with the burst was eliminated. With the addition of this new tool, the contractor was able to successfully complete the 300-m installation. The old and new configurations of the bursting heads are illustrated in Fig. 7.

Case Study No. 2: Installation of Sectional HDPE Pipe by Manhole Entry

Background

One of the main advantages trenchless construction techniques have over conventional open cut methods is in

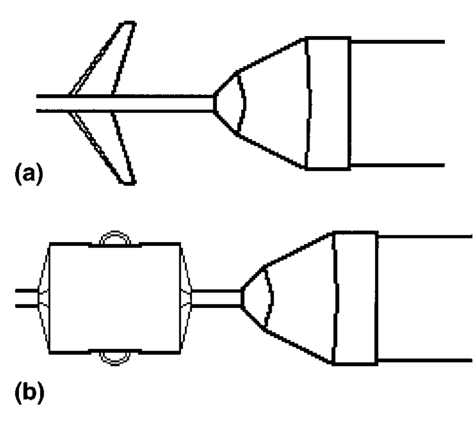

FIG. 7. Innovative Bursting Head Configurations: (a) Cutting Fins; (b) Cutting Wheels

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the reduction of social costs. Trenchless methods can minimize surface disruption, limit road closure, and minimize subsurface soil movements in situations where utilities are in close proximity to the pipe being rehabilitated or replaced. In 1997, the city of Calgary, Alberta, was faced with the problem of an aging 300-mm-diameter clay sewer line that ran beneath Centre Street in the city's downtown core. Being a major arterial route, closing the street to replace the 70 m of pipe by open cut methods was not an option. In addition, access was severely limited due to the density of underground utilities that ran along the street. Access to the line could only be achieved through one manhole and through a small access pit at one end of the pipe to be replaced. As a result, a trenchless construction process was the only viable option.

Difficulties and Solutions

Originally, the project was bid to use a trenchless lining method to rehabilitate the aging sewer line. This method could rehabilitate the line considering the inherent limited access to the line. Preconstruction videos revealed the line to be structurally intact, and, subsequently, the line was cleaned and prepared for the liner. Soon afterward, it was discovered that there was one pipe segment that was completely deteriorated, past the integrity that would facilitate lining. After experimenting with different lining and slip lining methods, it was deemed another process would have to be employed to replace this section of pipe.

Pipe bursting was chosen as the alternative method to replace the line. Typically, when a section of line is burst, there is access pits at both ends of the line for machine and insertion pits. In this situation; however, due to the extreme utility congestion around the manhole at one end of the line, an access pit could not be excavated. As a result, Terraco Excavating Ltd., the bursting contractor for this project, had to employ a method that would facilitate the replacement of the pipe under these conditions.

To solve this problem, Terraco proposed that sectional pipe be used as the product line and be inserted through the manhole. They used a rigid polyethylene pipe, of 12.5-mm wall thickness, that was specially manufactured into 1,200-mm-long sections for easy handling in the manhole. A high capacity pulling machine was inserted in the access pit at the opposite end and was used to pull the bursting head and the pipe segments simultaneously. To keep the pipe segments together, 1,200-mm-long rods from a smaller bursting machine were attached to the back of the bursting head and run back through the new HDPE pipe to a backing plate that was snug against the lip of the last section of HDPE. Therefore, for each 1,200-mm advancement of the bursting head, one section of rod and pipe was added through the manhole access until the burst was completed. Due to the difficult soil conditions encountered, polymer was used as a lubricant to aid in the installation. A hose approximately 40 mm in diameter, containing polymer lubricant, was run through each new section of pipe prior to installation so as to facilitate the transfer of polymer to the bursting head through the backing plate. Polymer was distributed on the outside of the bursting head through pipe fittings that were specifically installed in the bursting head for this project. Terraco successfully completed the installation using this method.

Case Study No. 3: Size for Size Replacement Utilizing 600-mm-Diameter Sectional Clay Pipe

Background

In 1992, the city of Phoenix undertook a condition assessment program to determine the condition of its large diameter concrete sewer pipes. From this study, it was discovered that some sections of this infrastructure required maintenance and, in some cases, replacement. The city of Phoenix does not allow the use of HDPE in buried sewer applications due to unqiue soil and sewer flow characteristics, but rather prefers to use clay or VCP for these direct bury applications (Holstad and Webb 1998). In a process to evaluate the feasibility of pipe bursting compared to slip lining and other cured-in-place lining methods, a section was designated to test the pipe replacement technique for the installation of VCP.

The section selected for pipe bursting consisted of a 158-m length of 600-mm-diameter reinforced concrete pipe with 2.75 m of soil cover comprising a clayey sand with weak cementation. To preserve flow capacity, the replacement pipe diameter was maintained at 600 mm. Working with the Water Services Department of the city of Phoenix, Albuquerque Underground Inc. was awarded a contract to attempt the burst using a static bursting push-and-pull technique that facilitated the installation of sectional VCP pipe (Miller 1998). The length was subdivided into two sections of smaller lengths as per the geometry of the pipe alignment. The first section to be burst was 56 m in length and was designated as the test section to determine if the remaining 102 m was feasible to finish with the pipe bursting technique.

Difficulties and Solutions

As the burst progressed on the 56-m section, the bursting head advanced to the first service pit. It was observed that the pipe and busting head were offset in vertical alignment. In addition to this, there was substantial surface heave occurring directly above the crown of the pipe resulting in cracks opening along the road. The surface upheaval was a direct consequence of the bursting head being out of vertical alignment.

Prior to the burst being conducted, it was anticipated that there was sufficient soil cover to prevent surface heaving and keep the bursting head at the correct line and grade. After some investigation, it was determined that the invert of the reinforced concrete pipe did not break as the bursting head progressed, thus acting as a wedge and, subsequently, pushing the bursting head toward the surface. In addition, the geometry of the installation for the orig-

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inal pipe also assisted in the movement of the soil upward during the burst. It was concluded that in all probability the original pipe was installed in a vertically walled trench with the invert of the pipe placed directly on the base of the trench. With the vertical walls on the original trench, there was less resistance to soil displacement toward the surface than laterally or to the trench floor. Therefore, as the burst progressed, the displaced soil took the path of least resistance causing the soil mass to shear at the trench wall and displace this soil to the surface, resulting in surface upheaval. These concepts are illustrated in Figs. 8(a and b) showing, respectively, the original installation configuration and the soil movements resulting from the pipe configuration during the burst.

To solve the problem of the surface upheaval and maintain the proper grade and flow characteristics of the sewer, two issues had to be addressed. First, it was required that the line and grade of the pipe be maintained by increasing the stability of the bursting head, and, second, to ensure the proper vertical alignment, the existing pipe had to be burst or split at the invert. If the stability of the bursting head could be increased, the second problem would resolve itself. To increase the stability and downward pressure of the bursting head, it was modified to provide the advantage of a longer lever arm to assist in guiding the head. The leading and trailing edges of the bursting head were lengthened such that there was a longer section of the bursting head in the original pipe as well as a longer tail behind. This resulted in a larger surface area above the bursting head and a leading edge that would ensure that the bursting head maintained the proper grade and level throughout the pull. In addition, a cutting fin was added to the bottom of the head to break the pipe at the invert. With the additional downward force and resulting pressure, the cutting fin would be able to break the invert of the concrete pipe and maintain the new pipe at the same grade as the original pipe along the floor of the original trench.

After the modifications were completed, the second section was burst with success. Surface heave was eliminated, and it was estimated that the combination of lengthening the bursting head and adding the fin resulted in the pipe being installed at or near the original floor of the trench (Holstad and Webb 1998).

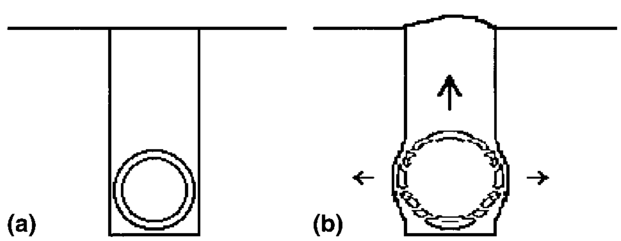

FIG. 8. Original Pipe Installation and Resulting Ground Movements

CONCLUSIONS

The application of trenchless pipe replacement in the rehabilitation of underground infrastructure can result in significant savings in both monetary and social costs, as well as time. In comparison to open cut trenching solutions, the unique nature of pipe bursting requires considerations that are unlike conventional replacement options. A major advantage that pipe bursting presents over other methods of pipeline renewal is its capability to increase flow capacity through upsizing and to install a new line that functions independently of the original pipe. The technique can be used to replace pipes of various composition and sizes, with new pipe materials that can be of either sectional or continuous nature, in both main line and lateral replacement applications. Sequencing of pipe installation segments on a particular project is highly dependent on the geometry of the original installation. During installation, the designer or planner must be aware of the risk of damaging the new pipe as well as the ground movements that occur during the operation to ensure a successful installation. Lessons learned from projects that required engineered solutions are invaluable in developing the technology to provide new applications in the trenchless rehabilitation arena. Through case histories and their discussion with the industry, the advantages of the application of trenchless pipe replacement as a viable alternative to conventional pipe installation and rehabilitation methods will be achieved.

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