Chapter 16

Pipe Bursting

Introduction

Underground service utilities in many American cities have been in place for over 100 years. While existing systems have functioned well beyond reasonably anticipated service life, underground systems are mostly deteriorated and need costly maintenance and repair. Common problems involve corrosion and deterioration of pipe materials, failure or leakage of pipe joints, and reduction of flow due to mineral deposits and debris build up inside the pipe. Damage to existing pipes can also occur by ground movements due to adjacent construction activity, uneven settlement or other ground instability. This leads to infiltration and inflow (I&I) increase in sewer systems. In water systems, it leads to flow and pressure reductions, persistent leakage (up to 30 percent of water provided in some systems), pipe bursts, and poor water quality. These problems tend to increase with the age of the network where maintaining this large network of underground sewer, water, and gas pipelines is difficult and costly. The above problems are compounded by the significant negative impacts (of open cut repair or replacement projects) on the daily life, traffic, and commerce of the area served by and along the pipeline in question.

Pipe bursting is a well-established trenchless method that is widely used for the replacement of deteriorated pipes with a new pipe of the same or larger diameter. Pipe bursting is an economic pipe replacement alternative that reduces disturbance to business and residents when it is compared to the open cut technique. Pipe bursting is especially cost-effective if the existing pipe is out of capacity, deep, and/or below the ground water table (GWT). Replacing an old pipe with a larger one is termed upsizing. One-size upsizing is replacing the old pipe with a pipe one standard size larger, for example replacing 8” pipe with 10” one. Similarly, two-size upsizing is replacing the old pipe with a pipe two standard sizes larger, e.g. replacing 8” pipe with 12” one.

Pipe bursting conventionally involves the insertion of a cone shaped bursting head into an old pipe. The base of the cone is larger than the inside diameter of the old pipe and slightly larger than the outside diameter of the new pipe to reduce friction and to provide space for maneuvering the pipe. The back end of the bursting head is connected to the new Polyethylene (PE) pipe and the front end is attached to a cable or pulling rod. The new pipe and bursting head are launched from the insertion shaft and the cable or pulling rod is pulled from the pulling shaft, as shown in Figure 1. The bursting head receives energy to break the old pipe from one of the following sources: a pulling cable or rod, a hydraulic source, or an air compressor. The energy breaks the old pipe into pieces and expands the diameter of the cavity. As the bursting head is pulled through the old pipe debris, it creates a bigger cavity through which the new pipe is simultaneously pulled from the insertion shaft. There are many variations to this conventional layout that are presented later in the chapter.

History

Pipe bursting was first developed in the UK in the late 1970s by D. J. Ryan & Sons in conjunction with British Gas, for the replacement of small-diameter, 3- and 4-inch cast iron gas mains (Howell 1995). The process involved a pneumatically driven, cone-shaped bursting head operated by a reciprocating impact process. This method was patented in the UK in 1981 and in the United States in 1986; these patents expired in April, 2005. When it was first introduced, this method was used only in replacing cast iron gas distribution lines; it was later employed to replace water and sewer lines. By 1985, the process was further developed to install up to 16-inch outer diameter (OD) medium-density polyethylene (MDPE) sewer pipe. Replacement of sewers in the UK using sectional pipes as opposed to continuously welded PE pipe was described in a paper by Boot et al. (1987). Up to 2006, approximately 9,000 miles of PE pipe has been installed by bursting (Najafi, 2006). Currently, pipe bursting is used to replace water lines, gas lines, and sewer lines throughout the world.

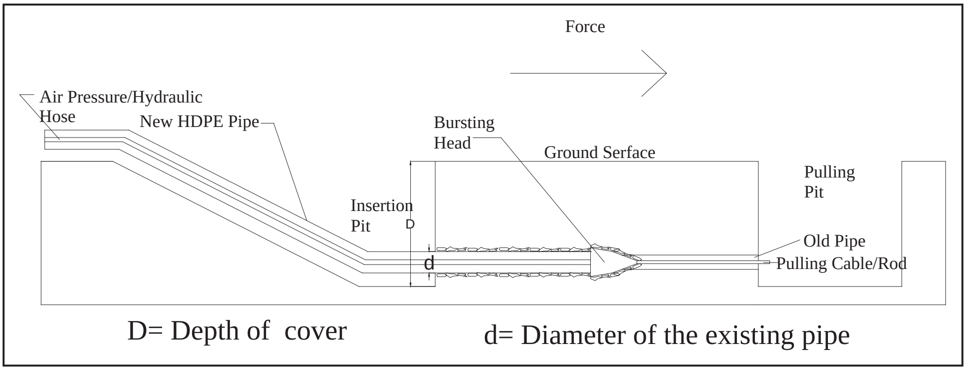

Figure 1 The Pipe Bursting Operation Layout

Pipe Bursting and Trenchless Pipe Replacement Systems

Existing old pipes can be replaced by one of several trenchless techniques developed up to date. There are three basic methods of pipe bursting: pneumatic, hydraulic, and static pull. In addition, there are proprietary trenchless pipe replacement systems that incorporate significant modifications to the basic pipe bursting technique. The basic difference among these systems is in the source of energy and the method of breaking the old pipe and some consequent differences in operation that are briefly described in the following paragraphs. The selection of a specific replacement method depends on soil conditions, groundwater conditions, degree of upsizing required, type of new pipe, construction of the existing pipeline, depth of the pipeline, availability of experienced contractors, and so on.

Pneumatic Bursting Systems

The most common pipe bursting method is the pneumatic system. In the pneumatic system, the bursting tool is a soil displacement hammer driven by compressed air and operated at a rate of 180 to 580 blows per minute. It is similar to a pile-driving operation going horizontally. The percussive action of the hammering cone-shaped head is also similar to hammering a nail into the wall; each hammer pushes the nail a short distance as shown in Figure 2. With each stroke, the bursting tool cracks and breaks the old pipe, the expander on the head - combined with the percussive action of the bursting tool, push the fragments and the surrounding soil providing space to pull in the new PE pipe. The expander can be frontend (attached to the frontend of the hammer) for pipes smaller than 12" or back-end (attached to the backend of the hammer) for pipes larger than 12". The frontend expander allows withdrawing the hammer through the PE pipe after removing the expander from the existing manhole at the pulling shaft without damaging the manhole. The tension applied to the cable keeps the bursting head aligned with the old pipe, keeps the bursting tool pressed against the existing pipe wall, and pulls the new PE pipe behind the head. An air pressure supply hose is inserted through the PE pipe and connected to the bursting tool. The bursting starts once (1) the head is attached to the new pipe, (2) the winch cable is inserted through the old pipe and attached to the head, (3) the air compressor and the winch are set at a constant pressure and tension values. The process continues with little operator intervention until the head reaches the pulling shaft at which point it is separated from the PE Pipe.

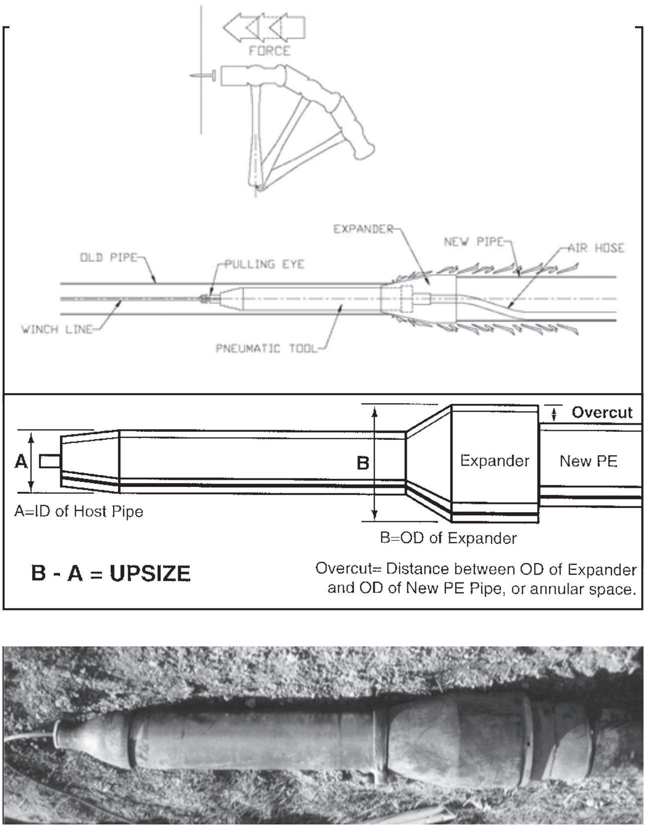

Figure 2 The Bursting Head of the Pneumatic System

Static Bursting Systems

The second common method of pipe bursting is the static pull system. In the static pull system, a larger tensile force is applied to the cone-shaped expansion head through a pulling rod assembly or cable inserted through the existing pipe. The cone transfers the horizontal pulling force into a radial force -- breaking the old pipe and expanding the cavity providing space for the PE pipe as shown in Figure 3. The steel rods, each is about four feet long, are inserted into the old pipe from the pulling shaft. The rods are connected together using different types of connections. When the rods reach the insertion shaft, the bursting head is connected to the rods and the PE pipe is connected to the rear of the head. A hydraulic unit in the pulling shaft pulls the rods one rod at a time, and the rod sections are removed. The process continues until the bursting head reaches the pulling shaft, where it is separated from the PE pipe. If cable is used instead of rod, the pulling process continues with minimum interruption, but the tensile force of a cable compared to a rod section is limited.

Pipe Splitting

The North American Society for Trenchless Technology (NASTT) defines *pipe splitting* as a replacement method for breaking an existing pipe by longitudinal slitting. At the same time a new pipe of the same or larger diameter may be drawn in behind the splitting tool (NASTT 2008). Pipe splitting is used to replace ductile material pipes, which does not fracture using the above-cited bursting techniques. The system has a splitting wheel or cutting knives that slit the pipe longitudinally at two more lines along the side of the pipe. An example of splitting head is shown in Figure 4.

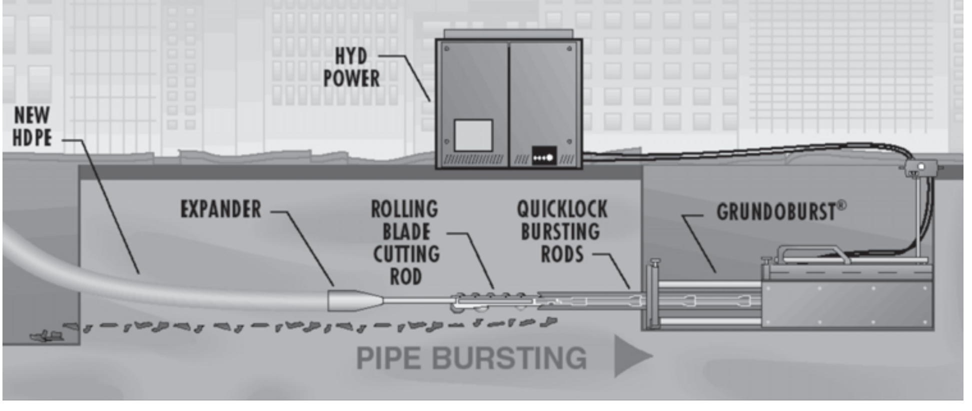

Figure 3 The Static Pull Bursting Head with Accessories to Cut Reinforcing Steel in RCP

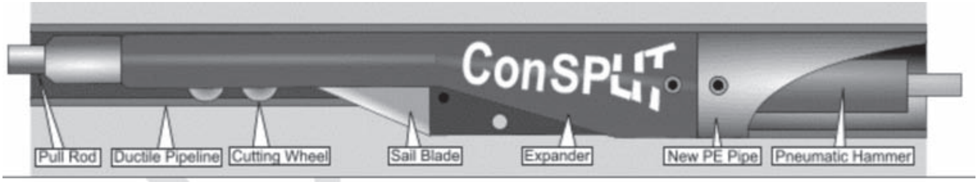

Figure 4 Pipe Splitting Head (PIM Corporation 2007)

Pipe Reaming

Pipe reaming is pipe replacement technique that uses a horizontal directional drilling (HDD) machine with minor modification. After pushing the drill rods through the old pipeline and connecting the rods to a special reamer (see Figure 5), the new PE pipe string is attached to the reamer via a swivel and towing head. As the drill rig rotates and simultaneously pulls back, the old pipe is grinded and replaced by the new PE pipe. Removal of the old pipe is accomplished by mixing the grinded material with the drilling fluid and transferring it to an exit point for removal via a vacuum truck. Directional drilling contractors or utility contractors who use an HDD rig can add inexpensively modified reamers of various types for different pipe materials and ground conditions. Pipe reaming is limited to non-metallic pipeline replacement. According to Nowak (Hayward 2002), the surrounding environmental conditions (groundwater, sand, rock, concrete encasement, etc) that prohibit other procedures are not obstacles to successful installations.

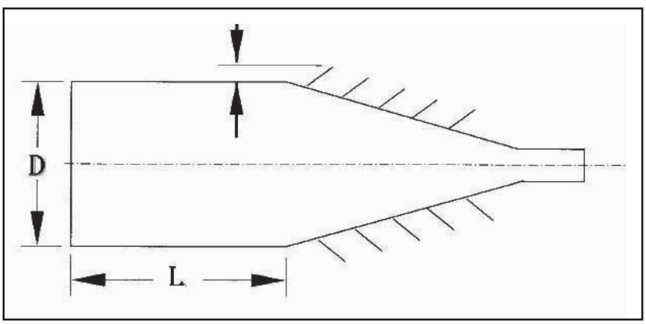

Figure 5 Reaming Head

Impactor Process

The patented Impactor process is another system that combines the HDD with pipe bursting as shown in Figure 6. The bursting head (Impactor) receives air through the HDD stems. The HDD is connected to the air supply and positioned to drill out to an entry manhole. Then the HDD stem is pushed through old pipe to the next manhole and drilled back to the entry manhole. The Impactor device, after it is attached to the drill stem and to the replacement pipe, is pulled into the old pipe. While pulling back, the Impactor system is activated and bursts the old pipe. The combined actions - of pulling using the HDD rig and of hammering of the Impactor device - breaks up the old pipe and replace it with the new pipe. The Impactor system can reduce excavation and overcomes blocked old pipes.

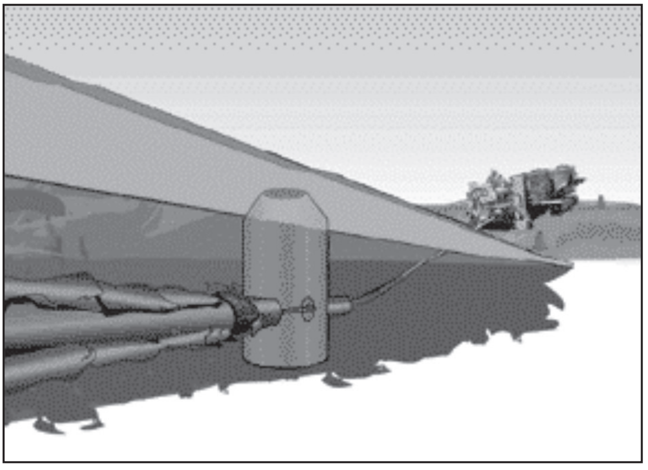

Figure 6 The Impactor Process Combines HDD with Pipe Bursting

Old Pipe Material

In most bursting applications, the old pipe is made of a rigid material such as vitrified clay pipe (VCP), ductile iron, cast iron, plain concrete, asbestos, or some plastics. Reinforced concrete pipe (RCP) was successfully replaced when it was not heavily reinforced or if it was substantially deteriorated. The diameter of the old pipe typically ranges from 2 inches to 30 inches, although the bursting of larger diameters is increasing. A length of 300 to 400 feet is a typical length for bursting; however, much longer runs were completed with bursting systems that are more powerful. In addition, some point repairs on the old pipe, especially repairs made with ductile materials, can make the process more difficult.

New Pipe Material

High-and medium-density polyethylene (HDPE and MDPE) have been the most-used replacement pipes for pipe bursting applications. The main advantages of PE pipe are its continuity, flexibility, and versatility. The continuity, which is obtained by butt fusing together long segments in the field, reduces the possibility of stopping the process. The flexibility allows bending the pipe for angled insertion in the field. In addition, it is a versatile material that meets all the other requirements for gas, water, and wastewater lines. The smoother interior surface (relative to other pipe material) reduces the friction between the flow and the pipe wall, which allow higher flow speed and increased flow capacity. The PE pipe does not erode, rotten, corrode, or rust; it also does not support bacteriological growth. The relatively higher thermal expansion coefficients are the main issue with PE pipes, but when the PE pipe is installed and restrained appropriately, the pipe expands and contracts without any damage. When used in pipe bursting applications, the friction between the soil and the pipe is reduced.

The internal surface of the PE pipe is smoother than those of the concrete or clay pipes. For gravity applications, after some algebraic manipulation to the following Chezy-Manning equation, it is can be demonstrated that the flow capacity of the PE is 44% more than those of the concrete or clay pipes considering the internal diameter for the old clay or concrete pipe equals that of the replacement PE pipe.

$$Q = \frac{1.49}{n} A(r_H)^{2/3} \sqrt{S}$$

WHERE

Q = the flow quantity
n = Manning roughness coefficient
A = the area of the pipe
r_H = hydraulic radius
S = the slope of the energy line, which is parallel to the water surface and pipe invert if the flow is uniform.

The n value ranges for clay or concrete pipes between 0.012 and 0.015 (on average about 0.013), and it is about 0.009 for PE (Lindeburg 1992).

In addition to PE, other new pipe materials can be ductile iron, VCP, or RCP. However, these pipes cannot be assembled into a single pipe string prior to bursting operation; but they can be jacked into position behind the bursting head or kept compressed by towing them via a cap connected to the cable or rod that passes through the pipes. Therefore, the static pull system is the only bursting system that can be used with these pipes. The joints of these pipes must be designed for trenchless installations.

When is Pipe Bursting a Preferred Solution?

For repair and replacement, conventional techniques have involved open cut excavation to expose and replace the pipe. Alternatively, the pipeline can be rehabilitated by inserting a new lining or replaced by pipe bursting. There are several pipe lining technologies available such as cured in place pipe, deform and reform, and slip lining. The main advantage of the lining methods over pipe bursting is the need for small or no access excavation to the pipeline. In contrast, pipe bursting has the advantage of increasing the pipe capacity by more than 100%.

The unique advantage of pipe bursting over pipe lining techniques is the ability to upsize the service lines. A 15% and 41% upsizing doubles the capacity of the sewer and water lines respectively. The technique is most cost advantageous compared to the lining techniques when (1) there are few lateral connections to be reconnected within a replacement section, (2) the old pipe is structurally deteriorated, and (3) additional capacity is needed.

For pressure applications, 41% increase in the inside pipe diameter double the cross sectional area of the pipe and consequently double the flow capacity of the pipe. For gravity applications, after some algebraic manipulation to the above-mentioned Chezy-Manning equation, it shown that a 15% and 32% increase in the inside diameter of the pipe combined with the smoother pipe surface can produce a 100% and 200 % increase in the flow capacity, respectively.

Pipe bursting has substantial advantages over open cut replacements; it is much faster, more efficient, and often less expensive than open cut especially in sewer applications due to high depths that usually gravity sewer pipes are installed. The increased sewer depth requires extra excavation, shoring, and dewatering which substantially increases the cost of open cut replacement. The increased depth has a minimal effect on the cost per foot for pipe bursting as shown in Figure 7 (Poole et al 1985). Specific studies carried out in the US have shown that pipe bursting cost savings are as high as 44% with an average savings of 25% compared to open cut (Fraser et al 1992). This cost saving could be much more if the soil is hard rock because rock excavation is extremely expensive compared to pipe bursting. Additionally, open cut can cause significant damage to nearby buildings and structures (Atalah 2004).

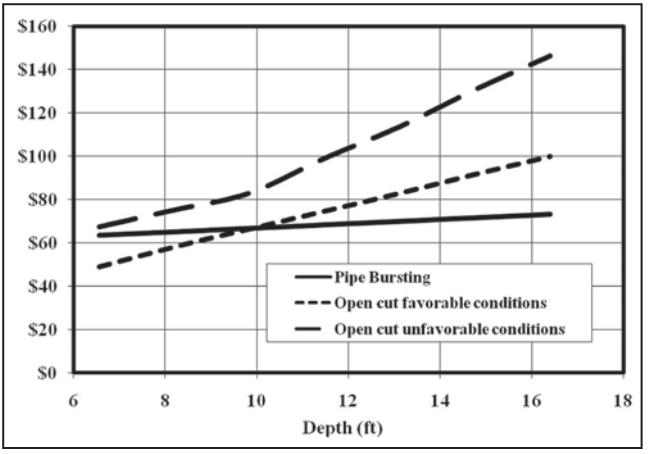

Figure 7 Cost Comparison Between Pipe Bursting and Open Cut Replacements (Poole et al 1985)

In addition to the direct cost advantage of pipe bursting over open cut, pipe bursting, as a trenchless technique, has several indirect cost savings. Less traffic disturbance, road or lane closing, time for replacement, business interruption, and environmental intrusion are some examples of these indirect cost savings. Pipe bursting has minimal interference with other utilities, and less safety hazards (for both operators and the public) due to reduced open excavation.

The unique advantage of pipe bursting over pipe lining techniques; such as cured-in-place pipe (CIPP), sliplining, and deform and reform, etc.; is the ability to upsize the service lines. A 15% and 41% upsizing doubles the capacity of the sewer and water lines respectively. The technique is most cost advantageous compared to the lining techniques when (1) there are few lateral connections to be reconnected within a replacement section, (2) the old pipe is structurally deteriorated, and (3) additional capacity is needed. Pipe bursting has the following additional advantages over open cut: (1) minimal disruption to traffic, (2) minimal interference with other utilities, (3) superior safety (for both operators and the public) due to reduced open excavation, and (4) substantial time savings.

Pipe Bursting Project Classification

National Association of Sewer Service Companies (NASSCO) classified bursting projects into three classifications in terms of difficulty; they are A – routine, B - moderately difficult to challenging, and C – challenging to extremely challenging. The projects are classified as A - routine if the depth is less than 12 feet, the existing pipe is 4-12 inch in diameter, the new pipe is same size as the old pipe or one diameter upsize, the burst length is less than 350 feet, the old trench is significantly wider than the diameter of the new pipe, and the soil is compressible outside trench (soft clay, loose sand). The projects are classified as B - moderately difficult to challenging if the depth is between 12 feet and 18 feet, existing pipe is between 12 to 20 inch, the diameter of the new pipe is two diameter upsize, the burst length is between 350 feet to 450 feet, the trench width less than 4 inch wider than new pipe diameter, or the soil is moderately compressible outside trench such as medium dense to dense sand, medium to stiff clay. The projects are classified as C – Challenging to Extremely Challenging if the depth is more than 18 feet, existing pipe is between 20 and 36 inch, the new pipe diameter is three or more diameter upsize, the length is more than 450 feet, the soil is incompressible outside trench, or the trench width is less than or equal to upsize diameter. Note that the degree of difficulty increases as more than one of the above criteria applies (Najafi 2007).

TABLE 1
Summary of NASSCO Pipe Bursting Classification

Criteria	A – Routine (all of the criteria below apply)	B - Moderately Difficult to Challenging	C – Challenging to Extremely Challenging
Depth	Less than 12 feet	12 ft to 18 ft	More than 18 ft
Existing Pipe	4”-12”	12” to 20”	20”-36”
New Pipe Diameter	Size for size or one diameter upsize	Two diameter upsize	Three or more diameter upsize
Burst Length	Less than 350 feet	350 feet to 450 feet	More than 450 feet
Trench Width	Relatively wide trench compared to upsized diameter	Trench width less than 4” wider than upsize diameter	Incompressible soils (very dense sand, hard clay or rock) outside trench
Soil	Compressible soils outside trench (soft clay, loose sand)	Moderately compressible soils outside trench (medium dense to dense sand, medium to stiff clay)	Constricted trench geometry (width less than or equal to upsize diameter)

Pipe Bursting Applicability and Limitations

Pipe bursting is used to replace water lines, sewer mains, and gas lines, as well as sewer lateral connections. Typical replacement length is between 300 feet and 500 feet; however, in favorable conditions, longer drives have been completed successfully. The size of pipes being burst typically range from 2 to 30”, although pipes of larger sizes can be burst. Pipe bursting is commonly performed size-for-size and one-size upsize above the diameter of the existing pipe. Larger upsize (up to three pipe sizes) have been successful, but the larger the pipe upsizing, the more energy needed and the more ground movement will be experienced. It is important to pay close attention to the project surroundings, depth of installation, and soil conditions when replacing an existing pipe especially in unfavorable conditions such as expansive soils, repairs made with ductile material, collapsed pipe, concrete encasement, sleeves, and adjacent utility lines.

On the other hand, pipe bursting has the following specific limitations: (1) excavation for the lateral connections is needed, (2) expansive soils could cause difficulties for bursting, (3) a collapsed pipe at a certain point along the old pipe may require excavation at that point to allow the insertion of pulling cable or rod and to fix the pipe sag, (4) point repairs with ductile material can also interfere with the replacement process, (5) if the old sewer line is significantly out of line and grade, the new line will also tend to be out of line and grade although some corrections of localized sags are possible, and (6) insertion and pulling shafts are needed specially for larger bursts.

Design Considerations

Pipe-bursting projects can be broken down to three phases: pre-design, design, and construction. The pre-design phase involves collecting information about the problem pipeline, investigating the alternative solutions, and ensuring that pipe bursting is the best solution. The design phase involves investigating the conditions of the old pipe and trench, nearby utilities and structures, determining shaft locations, bypass pumping requirements, and developing detailed drawing and specifications. The construction phase involves selecting the bursting system, lateral connections, submittals, shaft construction and shoring, bypass pumping, and restoration.

Pre-design Phase

At the pre-design and design phases, the ability to influence the cost of the project is the highest, and the cost of project modification is lowest, as shown in Figure 8. This is especially true for small jobs where the contractor’s cost savings (from design modification) is small in magnitude, and the benefits do not justify the risk of being responsible for the redesign and its consequences. Therefore, invested effort in this phase will pay dividends later.

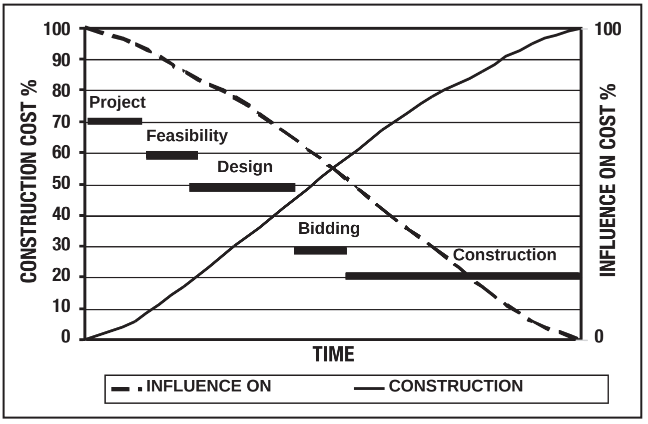

Figure 8 Ability to Influence Construction Cost Over Time (Project Management Institue Inc. 2004)

The pre-design phase involves collecting information about the old and new pipelines. The designer determines the maximum flow requirements for the future design life of the pipeline (considering the future economical developments and population growth trends), and then calculates the diameter of the new pipe. This phase also includes investigating potential solutions for the problem and collecting the relevant information to evaluate the valid solutions. For example, potential solutions may include installing another new line, lining the old pipe, replacing the pipeline via open cut, replacing it by pipe bursting, and so forth. If pipe bursting is the optimal solution, the design team proceeds to the design phase.

Many times open cut is the specified method of construction for most pipeline projects, and the bursting contractors offer pipe bursting as an alternative to open cut. This process may include preparation and submittal of two bids: one is based on open cut and the second is a value-engineering proposal based on pipe bursting. While this arrangement may increase the competition among bidding contractors, it increases the overall project cost (due to risk and contingency factors) for the project because (1) while the presented information in the contract document might be complete for the open cut method, it may be incomplete for estimating the cost of the bursting project and (2) this incomplete bid information increases the risk of problems during construction period that may lead to change orders and possible disputes that are more costly to resolve. It is believed that if the owner and the engineer select the methods of construction (for example open cut and pipe bursting) early during the design phase, the competition is maintained, bidding information is complete, and the risk of changes is reduced as illustrated in Figure 8.

Design Phase

The design phase starts with collecting further information about the old line, such as: the type of soil and backfill, current flow volume for bypass pumping, lateral connections, trench width, backfill compaction levels, and manhole locations. This phase also includes locating nearby utilities, investigating soil and trench backfill material, and developing risk assessment plans. The feasibility of pipe bursting as the optimal solution may need to be re-evaluated in light of the new collected information. The designer completes this phase with developing detailed drawing and specifications and complete bid documents which include listing of the needed submittals. The drawings should provide all relevant information, such as diameter and material type of existing pipe, existing plan view and profile, existing nearby utilities and structures (crossing and parallel), repair clamps, concrete encasement, fittings, and so forth. This information is collect through a CCTV or similar inspection of the old pipe.

Utility Survey

Surrounding utilities have significant impact on the success of the pipe bursting operation, and the design engineer should attempt to identify and locate these existing utilities. However, the *exact* location of these utilities must be identified during the construction phase through visual locating, such as vacuum potholing. The identification of nearby utilities by design engineer is critical for the following reasons:

- The presence of nearby utilities may steer the engineer to eliminate pipe bursting as a construction method.
- The existing utilities may affect the location of insertion and pulling/jacking shafts.
- Reduce or eliminate the risk of causing significant damage to these utilities.
- The contractors need to know the number of utilities that they need to expose to account for them in their bid.
- Consideration for protection of existing utilities from the ground movement of the bursting operation must be made early on to reduce the risk of service interruptions to the customers.
- Reduce the risk of injuries and fatalities to the workers and nearby people if these utilities are accidently damaged during bursting.

Site investigation should indicate the locations of many utilities; for example, sewer manholes indicate the presence of a sewer line and fire hydrants indicate the presence of a water line, etc. The engineer should contact the One-Call center for utilities marking, review the available as-built drawings from the different utility owners, and ideally consider geographic information system (GIS) data (if available), utility maps, and conducts surface and subsurface investigations to superimpose these utilities on plans and profiles.

Investigation of Existing Pipe and Site Conditions

Investigation of the old pipe condition assists in selecting the suitable rehabilitation technique and provides the exact location of the lateral connections. The conditions of the existing pipe may render pipe bursting as an unsuitable method for correcting the problem. The presence of sags in the line may require treatment for the sag prior to bursting. The host pipe (diameter, material, and conditions) and the diameter of the new pipe guide the contractor to select the appropriate bursting system type, size, and accessories during the bidding and construction phase. The site conditions and surface features may affect the locations of the insertion and pulling shafts, staging area for fused pipe, traffic control planes, and foot print for the needed bursting system components.

Insertion and Pulling Shaft Requirements

When planning for shaft locations, the engineer identifies spots where excavation is needed to replace manholes, valves, lateral connections, or fittings. These excavation spots are used as insertion or pulling shafts. However, if excavation at the manhole location is not feasible or needed, shaft excavation at other locations may be considered. In selecting the location of these shafts, the engineer has to consider the following issues:

- Sufficient staging area for the fused replacement pipe to avoid blocking driveways and intersecting roads.
- The shaft length should be long enough to allow alignment of the bursting head with old line and for the PE pipe to bend safely from the entry point to the ground surface.
- Space for the construction equipments such as backhoe, loader, crane, etc.
- Nearby flow bypass discharge spot or space to lay by pass lines without blocking driveways and intersecting roads.
- Traffic control around shafts.
- Soil borings close to these shafts.
- Discharge spots for dewatering if needed.
- Using the same shaft to insert or pull pipes more than once.

Generally, the engineer recommends locations for the insertion and pulling shaft but leaves the final determination to the contractor (through a submittal process) with the guidelines of minimizing excavation and disturbance to the surrounding environment.

Soil Considerations in Pipe Bursting

The soil and subsurface investigation is collecting the necessary information to properly design the project. It assists the contractor in submitting a proper bid by selecting the appropriate bursting system (type and size), shoring of the pulling and insertion shafts, dewatering system, compacting backfill material, etc. This proper decisions and biding increase the chances of success during the construction phase of the project.

The soil investigation activities include soil borings, standard penetration tests, groundwater level determinations, trench geometry investigation, and native soil and trench backfill material classifications. If the presence of washouts or voids around the existing pipe is suspected, Ground Penetrating Radar (GPR) survey may assist in determining locations and magnitude of these voids. Special attention should be given to the presence of major difficulties that may render pipe bursting not feasible such as the presence of rock, hard cemented dense soils, very soft or loose soils, reinforced concrete encasement, very narrow trench in hard soils or rock, or ductile point repairs. If contaminated soil is suspected, the type and extent of contamination should be identified and indicated in the contract documents. The contractor should be requested to take the necessary measures to handle and dispose of this contaminated soil.

The soil around the pipe (backfill and native soil) has to be compressible to absorb the diameter expansion. Compressible soils are the ideal soils for pipe bursting because the outward ground displacements will be limited to an area surrounding the pipe alignment as shown in Figure 9. Original backfill is the most suitable soil for bursting followed by (increasing difficulty) compressible clay, loose cobble, beach and running sand, densely compacted clay, then sandstone. Soils with long standup time allow the overcut (created by the expanded hole) to remain open for most of the bursting operation, thus reducing the friction force between the soil and the pipe. The overcut lowers the needed pulling forces and consequently the axial stress on the new pipe during installation. Somewhat less favorable ground conditions for pipe bursting involve densely compacted soils and backfills, soils below the water table and expandable soils. Special soils such as highly expansive soils or collapsible soils will also cause problems.

Pipe bursting below the groundwater table increases the difficulty of the bursting operations because the groundwater flows towards the insertion shaft requiring dewatering of the shaft. Also, in very soft or loose soils, significant ground movements may take place causing significant sags in the new line and damage to nearby structures. In sever situations, the soils particles migrate to the old pipe converting the bursting operation into a piercing operation. If the groundwater is lowered via any dewatering technique such as deep wells, well point system, or open sumps in the pulling and receiving shafts, the effective soil pressure will increase.

This will increase the vertical loads on the pipe causing increased friction, bursting and pulling force, and tensile stresses in the PE pipe. On the other hand, the presence of water reduces the coefficient of friction between the pipe and the soil, reducing the applied pulling force.

If the original soil borings (during the old pipe installation) are available, they should be reviewed and made part of the supplemental information available to the bidders. The determination of the trench geometry and backfill material and compaction is important for the designer and contractor.

Maximum Allowable Operating Pressure (MAOP)

For pressure applications such as water, gas, and force mains, the maximum allowable pressure should be determined based on the maximum surge pressure that pipe will be subject to and the maximum operating pressure for the pipe. The PE pipe should be designed to withstand the maximum allowable operating and surge pressures according to the design procedure shown in Chapter 6 in this Handbook. DR 17 is typically used for bursting pressure or gravity pipe unless a higher pressure rating is required. In short bursting runs where high tensile forces are not expected DR 21 can be used.

Risk Assessment Plan

Most underground and pipeline construction projects generally have some risks associated with the unknown subsurface conditions. The risks associated with pipe bursting include damage to nearby utilities and structures, failure to complete the project using pipe bursting, and time and/or budget overrun. There is risk of damage to nearby utilities, buried structures, and pavement if there are adverse soil conditions, improper construction techniques, design mistakes, inappropriate toning of utilities, etc. There are also many risks associated with flow bypass, dewatering, shoring, etc if the appropriate procedures were compromised. A list of additional risks that may stop the bursting operation and/or create problems include:

- Settlement at insertion/pulling pits if the density of the backfill exceeds that of native soil.
- Bursting through sharp curves.
- Concrete encasement or steel point repair inside existing pipe.
- Excessive bursting lengths.
- Damage to new pipe from sharp edge or fragments of existing pipe being burst/split.
- Damage to laterals from bursting of main line.

- The presence of rock under the existing pipe may create a 'bump' in the replacement pipe.
- Collapsed pipe.

Projects with class C classification-challenging to extremely challenging as indicated in Table 1- must be carefully examined in terms of required forces and ground displacements. Additionally, the depth of the old pipe affects the expansion of surrounding soil and consequently the extent of ground displacement around the pipe. If the pipe is shallow, damage to the pavement may take place. Saw cutting the pavement prior to bursting might be advisable. If the existing pipe is below the GWT, the difficulties increase. Insertion and pulling shafts grow larger and more complex as the depth increases.

If there are unacceptable sags in the existing sewer line, these sags need to be corrected before bursting. The sags can be corrected by local excavation, surface grouting, or grouting from within the pipe. Some reduction of sag magnitude may be expected (without corrective measures) from the bursting operation, but the extent to which the problem is corrected depends on the relative stiffness of the soil below the sagging section.

If there is erosion of the soil around the pipe, the bursting head and the following PE pipe will tend to deviate toward the void or lower density region. If there is a hard soil layer or rock close to the pipe, the bursting head will tend to displace towards the softer soil. In shallow conditions, the bursting head will deviate mostly upwards towards the ground surface. If the conditions change substantially along the length of the burst, this may cause some change in the grade and/or alignment of the pipe. When the grade is critical, these possibilities should be considered.

Most pipe bursting operations can be done safely if site and project conditions are known before bursting and appropriate measure are taken to address these conditions. There are well known solutions to all of the above mentioned risks and problems, and successful project engineers or construction managers identify these risks and develop a risk management plan to address these specific risks for this project. This plan includes quantification of the occurrence probability of the identified events and their associated impact or damage; it also includes measures to eliminate, mitigate, transfer, or undertake these risks. One of the general measures to mitigate the project risks is building and maintaining cooperative relationships among owners, engineers, contractors, equipment manufacturers, and pipe suppliers. Identifying and developing a realistic plan to manage and share risks appropriately is an important part of effectively communicating responsibilities, defining roles, and building a strong team. It is important to pay close attention to the project surroundings (surface and subsurface conditions) for unfavorable conditions and risks. These conditions require extra attention in order to ensure the safety of all involved people as well as surrounding facilities and infrastructure.

Ground Movement Associated with Pipe Bursting

The pipe bursting process creates a cavity in the soil around the pipe where the new pipe is pulled through. This cavity creates a compression plastic zone around the new pipe outlined by an elastic zone as shown in Figure 9.

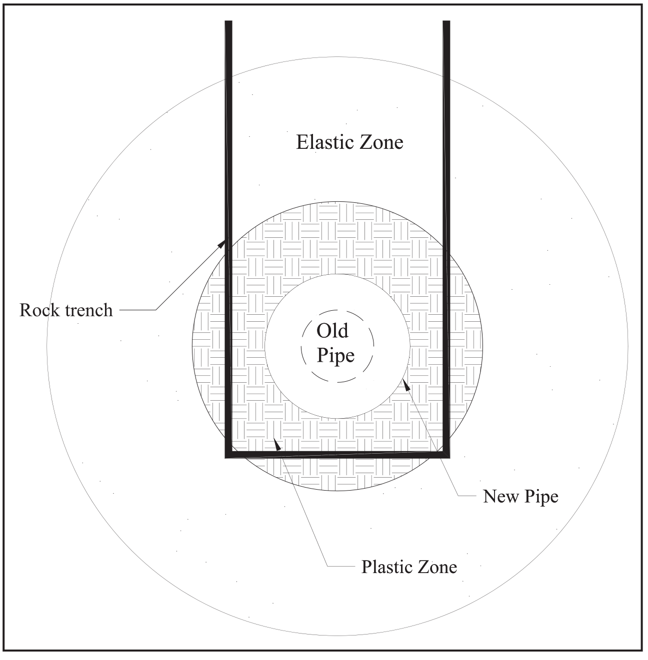

Figure 9 Cavity Expansion and the Plastic and Elastic Zones

The magnitude of the compression and the dimensions of these zones correlate with the amount of upsizing, the diameter of the pipe, and the type of soil (Atalah 1998). The author investigated the ground movements and vibrations associated with bursting small diameter pipes in soft soils (Atalah 1998) and with large diameter pipes in rock conditions (Atalah 2004) and developed guidelines for safe distance from existing nearby utilities, structures, and pavement. Large diameter bursting in rock conditions is applicable for upsizing 24″ in diameter reinforced RCP pipes with upsize percentage less than 50%. Small diameter bursting in soft soils refers to upsizing 8″ and 10″ in diameter VCP with upsize percentage less than 30%. The findings of these reports are summarized in Figure 10.

Figure 10 compares the peak particle velocity (PPS) of the soil versus the distance from the source of the vibration for different types of construction equipment and small diameter pipe bursting in soft soils and large diameter bursting in rock conditions. The PPS is the velocity of soil particles as they vibrate due to these construction activities. There is a strong correlation between the distance from the bursting head and the level of vibration for pneumatic bursting. As shown in Figure 10, the bursting vibration levels quickly fall to levels that do not cause damage to buildings. For structurally sound residential buildings, a safe distance (away from these structures) of eleven feet and eight feet are recommended for large diameter bursting in rock conditions and small diameter bursting in soft soils respectively. Safe distances of eight feet and four feet from nearby structurally sound commercial structures are recommended for bursting large diameter bursting in rock conditions and small diameter bursting in soft soils respectively. In addition, the statistical analysis indicates that the safe distance should be more than 7.5 feet from the buried structures. These pipes are mostly deep main lines installed in the right of way, which are usually far from the residential or commercial buildings.

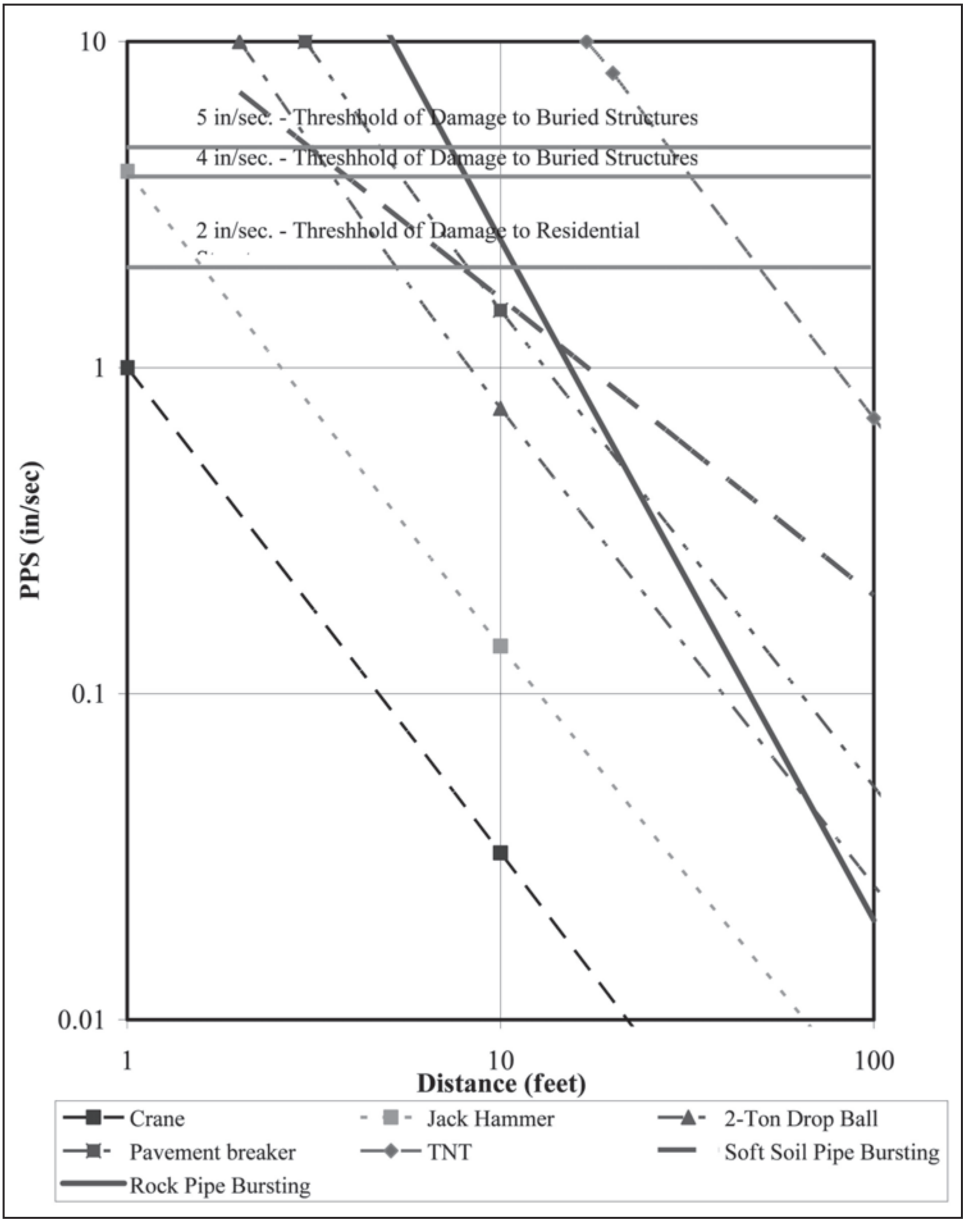

Figure 10 The Attenuation Lines of the PPS Versus Distance from the Source for Different Construction Pieces of Equipment (Wiss 1980) and the Attenuations of the 90% PI Upper Limit lines for the Pneumatic Bursting in Soft Soils (Atalah 1998) and Hard Soils (Atalah 2004).

Plans and Specifications

The contract documents typically include the contract agreement, general conditions, special conditions, project plans, specifications, geotechnical report, and CCTV records. The plans and specifications for pipe bursting projects should have all the required information for typical open cut water or wastewater pipeline projects plus the information listed in this section. The drawings should provide information about the existing site conditions and the required construction work. Description of site constraints (i.e., work hours, noise, etc.) and the procedures to review the CCTV data should be listed in the notes section in the drawings. The plans may also include information to show erosion and sediment control requirements, flow bypassing plans, and service connection and reinstatement details. Generally the plans should include:

- Limits of work; horizontal and vertical control references.
- Topography and survey points of existing structures.
- Boundaries, easements, and rights-of-way.
- Existing utilities, sizes, locations, and pipe materials.
- The verification requirements for existing utilities.
- Plan and profile of the design alignment.
- Existing point repairs, encasement, sleeves, etc.
- Construction easement and the allowable work areas around the insertion and pulling pits.
- Details for lateral connections and connections to the rest of the network.
- Restoration plans.
- Traffic control plans.
- Existing flow measurements for bypass pumping (Najafi 2007).

The technical specifications supplement the drawings in communicating the project requirements. Information to be included in the technical specifications should include:

General

- Minimum contractor qualifications.
- Permit matrix and responsibilities.
- Safety requirements with focus on confined space entry, flow bypass, and shoring.
- Scheduling requirements and construction sequence.
- Submittals.

Pipe and Manhole Materials

- Standards and tolerances for materials, wall thickness and class, testing and certification requirements.
- Construction installation instructions for pipe joining and handling.
- Fittings, appurtenances, and connection-adaptors.
- Acceptable material performance criteria and tests.

Construction Considerations

- Flow bypassing, downtime limits, and service reinstatement requirements.
- Spill and emergency response plans.
- Traffic control requirements.
- Erosion and sediment control requirements.
- Existing conditions documentation (e.g., photographs, videos, interviews).
- Protection plan for existing structure and utility (ground movement monitoring).
- Accuracy requirements of the installed pipe.
- Daily construction monitoring reports.
- Field testing and follow-up requirements for pipe joining, pipe leakage, disinfection, backfill, etc.
- Site restoration and spoil material disposal requirements (Najafi, 2007).

Submittals

In addition to the submittals needed for a traditional open cut projects, the submittals for pipe bursting projects usually include the following submittals: site layout plans, sequence of bursting, shoring design for all the excavations, bypass pumping plan, manufacturers' specifications of the selected bursting system and its components, dewatering plan, new pipe material, lateral connections material and plans, site layout plans, and so forth. The site layout plans would show the location of the insertion and pulling shafts, dimensions of shafts, traffic flow, safety and communication plan, storage space to store and lay the new pipe, and so forth. Lastly, the site restoration and clean-up plans should be included in the submittals

Quality Control/Quality Assurance Issues

The project specifications should state the quality control and assurance measures required to ensure that the project is executed according to the contract specifications. In addition to the quality control and quality assurance measures usually specified for a traditional open cut projects, there are a few measures that are specific to the pipe bursting operations. The project specifications should state the quality control and assurance measures required to ensure that the project is executed according to the contract specifications. These measures can take the form of tests, certifications, inspection procedures, etc. Extensive listing of the relevant required submittals, careful preparation of the submittals, and alert review and approval of the submittal are significant steps in the QC/QA program. The QC/QA program states the performance criteria for the product line and the acceptable tolerance from these criteria. For example, the invert of the new pipe should not deviate from the invert of the old pipe by more than a certain number of inches, the depth of sags in the line should not exceed one inch, and the difference in the vertical and horizontal dimensions of the new pipe diameter should not exceed 2%. The QC program should state how these performance criteria will be measured, tested, and checked. Some of these performance criteria that can be specified are post bursting CCTV inspection, pressure tests, and mandrel test. The surface and subsurface displacement-monitoring program should be outlined in the specifications along with the acceptable amount of ground movements. Certifications from the manufacturers of the bursting system, replacement pipe, and other material that these products meet the contract specifications based on tests conducted by the manufacturer or a third party may be required. For challenging projects, the presence of bursting system manufacturer representative at the jobsite may be required. The owner's quality assurance program should ensure that the field and management team of the contractor have the knowledge and the experience needed to complete the project successfully and able to respond appropriately to unforeseen problems.

Dispute Resolution Mechanisms

The contract should include different site conditions and unforeseen conditions clauses that allow contract time and amount adjustment if the conditions at site *materially* differ from the conditions expected and indicated in the bid documents. These clauses facilitate resolving disputes efficiently and quickly without negative impact on the project. If site conditions are significantly different than those described in the contract documents and the contractor or owner can show that the different conditions impacted the work, the contract value and duration should be adjusted accordingly. Conducting the proper surface and subsurface investigations, outlined earlier in this chapter, should minimize the occurrence of project disputes and possibility of work stoppage during the pipe bursting operations.

Maximum Allowable Tensile Pull

After the bursting head breaks the old pipe and creates a cavity in the ground, the winch pulls the new pipe through this cavity. For the pipe to be pulled, the pulling force has to exceed the friction between the outside surface of the pipe and the surrounding soils. When the coefficient of friction between soil and the pipe is high and the outside surface area of the pipe is large, high pulling forces are needed to overcome this high friction resistance. The high pulling force generates high tensile stresses on the replacement pipe. If the allowable tensile strength of the pipe is less than the anticipated tensile stresses on the pipe, actions to reduce friction must be adopted to avoid excessive strains in the pipe. Examples of these actions are increasing the diameter of the bursting head by about an inch to create about half an inch of overcut around the pipe, and injecting bentonite and/or polymer lubrication into the annular space behind the bursting head to reduce the frictional forces. If these actions are not sufficient to rectify the problem, shorter bursting run and relocation of the insertion or pulling shafts must be considered. Friction force calculations need to be conducted before bursting operation starts to avoid over stressing the pipe. It is much easier and less costly to incorporate the above-mentioned corrective actions before bursting than during bursting.

Typical safe pull tensile stress values for MDPE and HDPE are given in Table 2. Consult the manufacturer for specific applications. The values are given as a function of the duration of continuous loading. For pipe temperatures (not outside air temperatures) other than 73ºF, multiply the value in Table 2 by the temperature compensating multipliers found in Table B.1.2 of the Appendix to Chapter 3. The Safe Pull Load at 12 hours is given for many pipe sizes and DR's in Chapter 12, Tables 4 and 5 (3xxx material) and Tables 6 and 7 (4xxx material).

TABLE 2
Safe Pull Tensile Stress @ 73ºF

	Typical Safe Pull Stress (psi) @ 73ºF		
Duration (Hours)	**PE2xxx (PE2406)**	**PE3xxx (PE3408)**	**PE4xxx**
0.5	1100	1400	1500
1	1050	1350	1400
12	850	1100	1150
24	800	1050	1100

Note: The safe pull stress is the stress at 3% strain. For strains less than 3% the pipe will essentially have complete strain recovery after pullback. The stress values in Table 2 were determined by multiplying 3% times the apparent tensile modulus from the Appendix to Chapter 3 adjusted by a 0.60 factor to account for the high stress level during pullback.

Estimating the pulling force to break the old pipe and overcome friction resistance between the new PE and the surrounding soil is very difficult and currently there is no accurate method to calculate it. Many site and project factors interact to make developing an accurate and reliable model very difficult; among these factors: the strength of the old pipe, the type of backfill material, the type of native material, degree of upsize, bursting system, the amount of overcut, the presence of sags along the line, etc. Comparisons between the actual pulling forces and the calculated forces using the Terzaghi's Silo Theory that is used in calculating the jacking force in pipe jacking operations is presented later in this chapter.

Atalah et al (1998) instrumented two PE pipe with strain gauges and measured the strain in the pipe due to the pipe bursting process. They also calculated the friction resistance between the pipe and the soil using Terzaghi's silo theory. Figure 11 presents a comparison between the maximum stresses recorded in the pipe against calculated pipe stresses. The stress was calculated on the basis that the soil collapsed around the pipe and exerted a normal pressure on the pipe related to its depth below the ground surface similar to the frictional drag on jacking pipe. The assumptions for ground pressure and frictional resistance followed the typical assumptions for pipe jacking calculation presented in Atalah 1994 and Atalah 1996.

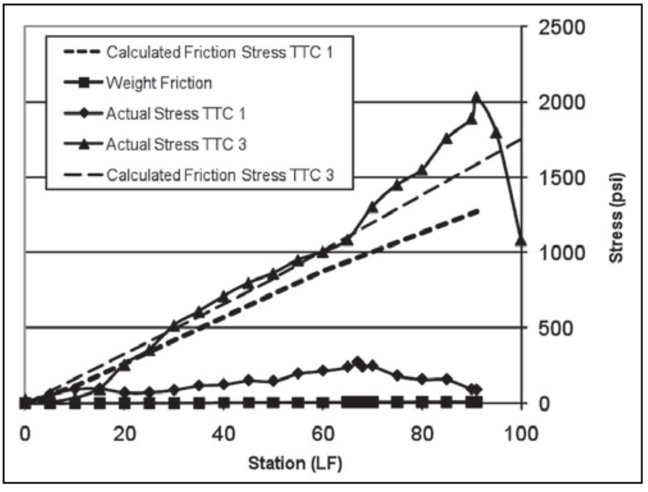

Figure 11 Actual Stress vs. Calculated Stress for TTC Test Site #1 and 3

As shown in the Figure 11 in TTC test site 1, there was substantially less frictional drag on the pipe than would be expected from a fully collapsed soil around the pipe. This indicated that the hole remained at least partially open during the replacement process. The cavity around the pipe stayed open during and possibly after the bursting because the nominal overcut was about 0.7 inch and the hammering action of the head compressed the surrounding soil. For the TTC test site 3, the measured data correlated well with the stresses that were generated from a collapsed soil around the replacement pipe over its full length. It is not clear why the friction on the pipe in this test is so much more than on the pipe in TTC Test Site #1 which had a larger upsizing. The following are the conclusions from these pipe stress measurements:

- Appear to match the range of stresses measured
- Measures to retard the collapse of soil around the replacement pipe will lower stresses in the replacement pipe

- None of the stresses measured exceeded about two-thirds of the yield stress of the PE pipe
- The level of stress in the replacement pipe was actually less for the pipe with larger upsizing percentage so there is not a direct relationship between upsizing percentage and replacement pipe stress
- The magnitude of the stress cycling in the replacement pipe during installation is small compared with the mean stress level

The pulling force must overcome the penetration resistance at the bursting head and the friction resistance along the outside surface of the pipe. The friction equals the outside surface area of the pipe times the soil pressure on the pipe times the friction coefficient between the soil and the pipe surface. A more detailed discussion about estimating the jacking force on jacking pipes is presented in Atalah 1994 and 1996. The frictional resistance, R, is calculated as follows:

$$R = \mu \times V$$

WHERE
μ = coefficient of friction.
V = the force perpendicular to the contact surface calculated using the Terzaghi's Silo Theory

There are two techniques to reduce the pulling force through the pipe: oversize cut and lubrication of the outside surface of the pipe. Oversize cut at the face reduces the puling force if the soil is highly stable. In unstable soil, oversize cut must be made nevertheless to allow lubricating the outside surface of the pipe, but it should be minimized. Lubrication around the whole perimeter of the pipe and along the whole length of the drive significantly reduces the friction resistance.

Permitting Issues

Permits from all the affected parties should be secured before the start of the bursting phase. Some of these permits could be secured by the owner and its representatives, and rest should be secured by the contractor. The permits responsibilities should be outlined in the specifications and stated on the drawings. Permits to burst under the road and to modify the regular traffic flow according to the project traffic control plan should be secured from owner of the affected road if the pipe crosses underneath a road. If the pipe crosses underneath a runway, taxiway, drainage ditch, irrigation channel or canal, and railroad track, permits should be secured from the owners of these facilities. Communications with the affected residents should take place before bursting to inform them about road closures, night or weekend work, service disruptions, driveway blockings and so on.

Typical Bidding Form For a Pipe Bursting Project

In addition to providing the owner with the total price of the project to compare the different bids, the bid form should provide the contractor and the owner with a mechanism for fair pricing and payment system based on the progress during construction. The unit prices in the form can also be used to resolve disputes amicably. It is recommended that the bursting is measured in linear feet and segmented by classification or sections from manhole to manhole or from insertion to pulling shaft. Segmentation by run or bursting class provides the owner and the contractor with fairer pricing mechanism and reduces and resolves disputes. Table 3 shows an example of a typical bid form for a pipe-bursting project (Bennett and Ariaratnam 2005).

TABLE 3
Example of Pipe Bursting Bid Form (Bennett and Ariaratnam 2005)

Item No.	Description	Quantity	Unit	Unit price	Total Price
1	Mobilization/Demobilization		LS		
2	Pipe Cleaning and Pre CCTV Inspection		LF		
3	Pipe Bursting of Exist. 6” VCP with New 9.05” O.D., SDR 17 PE Pipe (4’-8’ Deep) from MH 1 to MH 6		LF		
4	Pipe Bursting of Exist. 12” Class 250 Cast Iron Pipe with New 21.6” O.D. PE Pipe (8’-12’ Deep)		LF		
5	Pipe Bursting of Exist. 24” RCP with New 30” VCP (12’-16’ Deep) from MH 10 to MH 16		LF		
6	Pipe Bursting of Existing 4” Service Lateral with New 4.5” O.D., SDR 17 PE Pipe (4’-8’ Deep)		LF		
7	4” Lateral Connection to 9.05 O.D. SDR 17 PE Pipe (8’-12’ Deep)		EA		
8	6” Lateral Connection to Exist. MH		EA		
9	New PE Pipe Connection at MH		EA		
10	Furnish & Install 48” Dia. MH		EA		
11	Manhole Renewal		VF		
12	Cleaning, Testing and Post CCTV of New Sewer		LS		
13	Replacement of Unsuitable Trench Backfill Material		LS		
14	Bypass Pumping		LS		
15	Traffic Control		LS		
16	Pavement, Sidewalk and Curb Installation		LS		
17	Landscaping and Surface Restoration on Private Property		LS		

Please note that the lateral connections are accounted as a separate bid items and segmented by depth. Cleaning, testing, and post CCTV of the sewer line is a separate bid item. By pass pumping can be priced as a lump sum or measured by each run.

Selection of Pipe SDR

The PE pipes are available with iron pipe sized (IPS) or ductile iron pipe sized (DIPS) outside diameters. PE pipes are extruded with fixed outside diameter with variance in the inside diameter controlled by the Standard Dimensional Ratio (SDR) as shown in following equation:

$$SDR = \frac{\text{Pipe O.D.}}{\text{Wall Thickness of Pipe}}$$

The PE pipe should withstand the internal pressure requirements of the water or the force main line, overburden dead and live loads, and pulling forces during the bursting phase. The SDR of the PE pipe is a major factor in the ability of the pipe to withstand the installation forces and service pressures. Experience has shown that SDR 17 is sufficient for gravity sewer applications, and thinner wall pipes with SDR of 19 or 21 can be used in shorter and smaller diameter applications. Thinner wall pipes tend to stretch excessively during bursting. For pressure applications, if the maximum allowable design pressure is less than 100 psi, SDR of 17 is sufficient. If the maximum allowable design pressure is more than 100 psi, the allowable pressure governs the needed SDR. If the allowable pressure is 150 psi, PE pipe with SDR 11 meets needed pressure requirements.

In most trenchless applications, but not always, the pipe that withstands the pulling stresses during installation can withstand the vertical overburden and traffic pressures. The pipe stresses caused by construction are higher than those caused by vertical pressures. However, each application is different; it is possible that a specific application can require a different SDR. An engineering analysis is suggested for very deep or very shallow installations. Deep installations may be subject high overburden pressures, and shallow installations may be subject to high concentrated traffic loads that the pipe has to withstand.

Section 2 of Chapter 6 in this Handbook presents how to calculate the live loads on the pipe and stress distribution of live load with depth using the Timoshenko and Boussinesq equations to calculate the live load at the centerline of the pipe. The over burden pressure in trenchless applications can be calculated using the Terzaghi's Silo Theory.

Terzaghi's Silo Theory

Terzaghi established a calculation model to estimate the normal pressure acting on the pipe from vertical load and soil arch action. Terzaghi's theory presents the load on the pipe in a similar form to that of the horizontal earth pressure theory. The following equation gives the normal pressure on the pipe (P) as a function of soil density (w), depth of cover to center-line of the pipe (H), vertical live load at the pipe level (PL) and coefficient of soil load (k).

$$P = k\,(w\text{x}H + P_L)$$

The coefficient of soil load (k)

$$k = \frac{1 - e^{-2K \times \tan\delta \times H / B}}{2K \times \tan\delta \times H / B}$$

WHERE
K **= soil lateral pressure coefficient**
δ **= angle of wall friction between pipe and soil**
B **= the influence width above the pipe.**

According to the German Association for Water Pollution Control (ATVA 161), the values of these variables are: K = 0.5, δ = 0.5F (angle of internal friction of soil) and B= 1.73d (the outside diameter of the pipe). Figure 12 presents the value of k as a function of F and the ratio H/d for K= 0.5. On the other hand, in Japan, K= 1, δ= F and b= δ(0.5+tan(45-F/2) are used in the above equation. Although ground water does not significantly influence the soil friction, the ATVA 161 specifies, for safety reasons, that the full soil load should be applied in case of jacking below the ground water table. If the surrounding soil is swelling soil, additional swelling pressure must be considered (Stein 89).

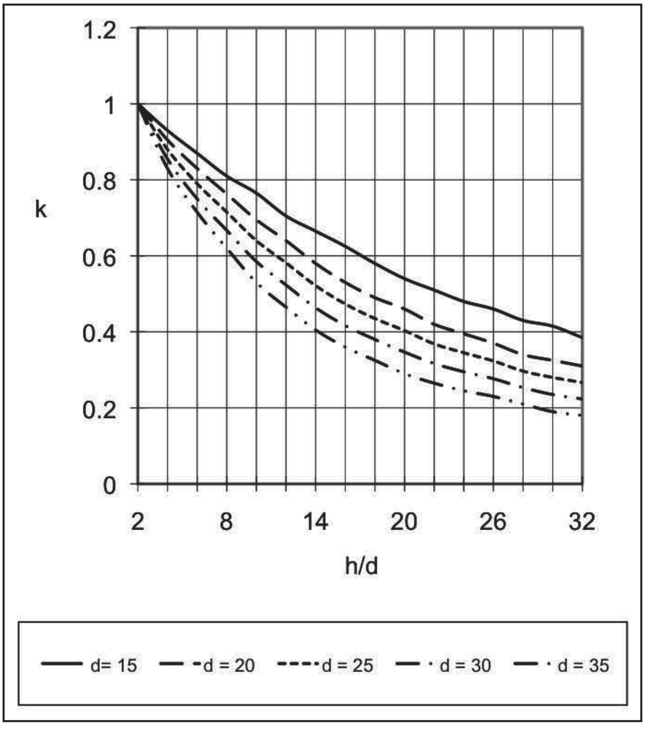

Figure 12 Reduction Factor k According to ATVA 161

Construction Considerations

Once the owner issues the notice to proceed, the contractor prepares the submittals for the project according to bid documents. Typically, the contractor takes the following steps:

- Pre-construction survey
- Cleaning or pigging of line, if needed
- Closed circuit TV inspection, if needed
- Excavations at services for temporary bypass
- Setting up temporary bypass or connections to customers
- Excavation of insertion and pulling shafts
- Fusion of PE
- Setting up the winch or hydraulic pulling unit and insertion of pulling cable or pulling rods inside the old pipe.
- Installation of hoses through the PE pipe to attach to bursting head (air supply hoses or hydraulic hoses for pneumatic or hydraulic systems respectively)

- Connection of bursting head to pulling cable or rod
- Pipe bursting and replacement with new pipe
- Removal of bursting head and hoses from the pipe
- Post installation inspection
- Pipeline chlorination if it is not pre-chlorinated (for water mains)
- Reconnection of services and reinstating manhole connections
- Site restoration

Butt fusion of PE replacement pipe is typically carried out prior to the bursting operation, so that all fused joints can be chlorinated (for water lines), checked, and tested. The pipe should not be dragged over the ground, and rollers, pipe cutouts, or slings should be used for both insertion and transportation of the pipe. The ends of water or gas pipes should be capped to prevent the entry of contaminants into the pipe.

Typical Pipe Bursting Operation Layout

The first step in planning the pipe bursting operation is the optimization of the locations of the insertion and pulling shafts by using the insertion shafts to insert the new pipe into two directions. This optimization reduces the amount of excavation, mobilization, and demobilization efforts. These shafts should be planned at manholes or lateral connections in sewer lines and at fire hydrants or gate valves in water applications. The length of the run between the insertion and pulling shafts should not generate friction forces that exceed the capabilities of the bursting system and the tensile strength of the pipe. The next step is ensuring that the area around every shaft is sufficient for safe operation of the needed pieces of equipment and material staging. The insertion shaft has a flat section and sloped section; the flat portion has to be long enough to allow aligning the centerlines of the bursting head with that of the old pipe. The slopped section has to be long enough to allow the PE pipe to bend without any negative impact on the pipe (i.e. accommodate the bending radius requirements of the pipe). PE pipes can be cold bent to a radius of 25 to 30 times the OD of the pipe depending on its SDR. Because of the pipe's ability to bend, the lay down area of the pipe prior to insertion does not necessarily have to be in line with the existing pipe. For example for an 18" PE pipe with an SDR of 17, the minimum length of the insertion shaft is a horizontal length of 12 times the diameter of the new pipe (18 feet) plus a sloped length of 2.5 times the depth of the shaft as shown in Figure 13 (Bennett and Ariaratnam 2005). The width of the pit depends on the pipe diameter and required working space around the pipe. The pulling pit must be large enough to allow for operation of the winch or pull-back device, along with removal of the bursting head.

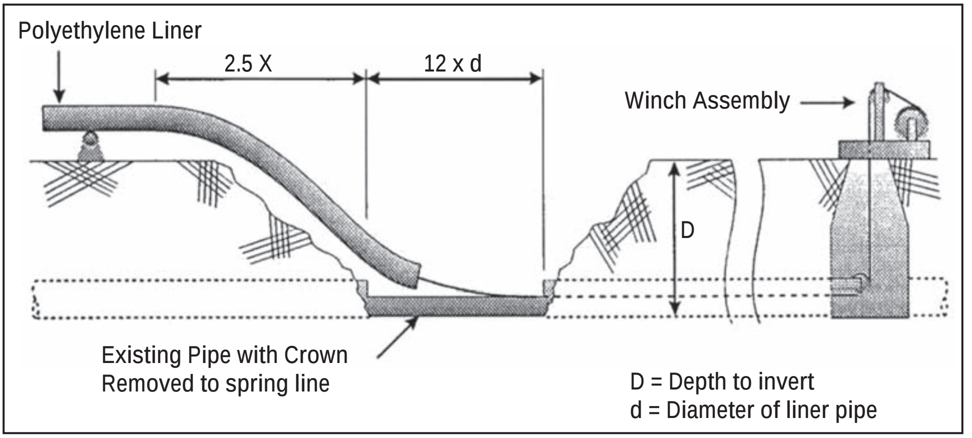

Figure 13 Insertion Shaft Dimensions for PE Pipe with SDR 17 (Bennett and Ariaratnam 2005)

Acceptable arrangements for traffic control, based on DOT and local government regulations, and for stretching the fused PE pipe with minimum inconvenience to nearby residents and businesses must be carefully considered. The flow bypass pumping and pipes layout should be also planned and considered. If dewatering needs arise, safe and proper flow discharge plans are required. The contractor submits the jobsite layout plan that reflects the intended method of construction and addresses the above mentioned considerations. The contractor does not start bursting before the engineer reviews and approves the jobsite layout plan, and the site inspector enforces the adherence to this plan unless there is a reason for the deviation approved by engineer or owner. If contaminated soil is excavated, the contractor should take the necessary measures to handle and dispose of this contaminated soil.

Shoring The Insertion and Pulling Shafts.

Proper shoring of the insertion and pulling shafts is essential for the safety of the workers and the safety of the surrounding environment. The trench shoring or bracing should be constructed to comply with OSHA standards. Some of the available means of shoring these shafts are: trench box, solder pile and lagging, steel sheet piles, corrugated pipes, etc. Also, if space is available, sloping the sides of the shaft to provide stability is an option. The judgment and the supervision of a competent person (as defined by OSHA) or a qualified geotechnical engineer is needed to ensure safe shoring.

In the pulling shafts, the winch will thrust against manhole wall or one side of the pulling shaft. This side has to be able to withstand the pressure coming from the pulling winch. Therefore, a thrust block or structure is needed to distribute the force over a larger area. In the static pull applications, the contractor should construct a thrust block against which the pulling system thrusts during pulling and bursting. The thrust block, shoring, and soil behind the shoring must be able to withstand the stresses from the pulling system. The passive earth pressure of the soil has to exceed the stresses generated by the pulling system with an acceptable factor of safety.

Matching System Components to Reduce Risk of Failure

One of the most critical activities before bursting is to ensure that the bursting system has sufficient power to burst the old run from the insertion shaft to the pulling shaft. The system must be able to overcome the friction between the soil and the outside surface of the new pipe and the soil with reasonable margin of safety to overcome unforeseen repair sleeves, clamps, etc.

The contractor should adhere to the sizing guidelines stated in the operations manual issued by the bursting system manufacturer to match the system with the needs of the job. The bursting system manufacturer should be consulted if there is any doubt regarding the adequacy of the system for that specific run in that particular conditions (soil, depth, type of pipe, etc.). Lubricating the outside surface of the pipe with polymer or bentonite (depending on the type of soil) can dramatically reduce the coefficient of friction between the pipe and the soil, and consequently, reduce the needed pulling force. In addition, the bursting system components should be appropriately matched to the need of the project; for example, the winch capacity is matched with the bursting head size and the conditions of the job.

Toning for Utilities

The contractor should do its due diligent to identify, locate, and verify the nearby underground utilities prior to digging the shafts and bursting. The contractor must contact the one state call center to have representatives of the nearby utilities come to the site and mark the existing utilities on the ground surface. Then the contractor has to verify the exact location and depth of these utilities via careful excavation. Manual excavation may be needed for the last few inches from the existing utilities to avoid damaging this utility. Vacuum excavation is an excellent tool to expose utilities with minimum surface excavation and minimum risk to the existing utility.

The underground utilities that are in moderate condition are unlikely to be damaged by vibrations at distances of greater than 2.5 feet from the bursting head in small (less than 12 inch in diameter) typical pneumatic pipe bursting operations (Atalah 1998). According to Atalah (2006), this safe distance for large diameter bursting (up to 24 inch) is about seven feet. Rogers (1995) reported that ground displacements are unlikely to cause problems at distances greater than 2-3 diameters from the pipe alignment. Utilities that are closer to the bursting head than these distances should be exposed prior to bursting so the vibration from the bursting operation would be isolated or reduced before it reaches the utility in question.

By Pass Pumping Considerations

One of the objectives of the bursting team (owner, engineer, contractor, etc.) is to minimize customers' service interruptions for water and gas applications and continuation of flow for sewer applications. The key for achieving this objective is the bypass pumping system. For water applications, the system should be able to deliver the needed flow volume with the specified pressure to the customers. For gravity applications, the system should be able to adequately pump the upstream flow and discharge it to the manhole downstream of the run being burst. The plan should ensure that the bypass system has adequate pumping capacity to handle the flow with emergency backup pumps to ensure no interruption to existing services. The bypass pipes and fittings should have sufficient strength to withstand the surge water pressures. Contractual arrangements between the owner and contractor should be made regarding third party damage due to the disconnection and reconnection of the water lines without fault of the contractor.

Dewatering Considerations

The pulling and the insertion shafts should be dry during installation to avoid disturbing the sub-grade in the shaft. Therefore, if rain is expected or the pipe invert is slightly below the GWT in clay soil, installation of a dewatering sump pump at one corner of the shaft is needed. Ditches crossing the shaft, sloped towards the sump, lined with filter fabric, and filled with gravel may be needed to direct the water towards the sump. If the pipe invert is significantly below the GWT in sandy or silty soils, more elaborate dewatering system is recommended such as well point system, deep wells, or larger sump and pump system. As the water level is drawn down, soil particles travel with the water towards the dewatering system undermining utilities and structures. As it is the case with every dewatering system, the contractor should take all necessary measure to prevent the migration of the soil particles from underneath nearby buildings and utilities. The discharge flow volume in this case is expected to be large; therefore, a suitable discharge in compliance with the EPA requirements is needed. If sump pump is used, preliminary treatment of flow to reduce the sediments may be needed before discharging into water streams.

Ground Movement Monitoring Program

The safety of nearby buildings and structures is paramount as it is the case in deep open cut installations. The safety of nearby structures can be compromised if the structures are subject more ground movements or vibration than what they can withstand. Referring to extremely challenging pipe bursting operations (class C—see Table 1), preconstruction survey and monitoring of the ground movement is advisable if there are nearby structures. A preconstruction survey of all nearby buildings and structures that documents all existing cracks, cosmetic problems, and structural deficiencies is recommended prior to any work on site. The elevations of carefully planned settlement points (on nearby buildings and on the ground surface) around the insertion and pulling shafts should be surveyed prior to bursting, during bursting, and after bursting. These preconstruction surveys and elevations monitoring can significantly reduce the risk of unmerited law suits to the contractor and the owner.

Pipe Connection to the Manhole

The thermal elasticity of the PE material causes changes in the pipe length; one inch change in length per 100 ft of pipe for each 10°F temperature change. Therefore, in extreme hot or cold weather when there is significant difference between the temperature of the deep soil and the ambient air temperature, it is recommended to allow the pipe to rest for 12 to 24 hours prior to tie-ins. Also when pipe has been pulled to a significant portion of its allowable tensile load, it may be prudent to let the pipe rest as well before connecting to other pipes, fittings, manholes, and lateral connection. This allows the pipe to rebound from any stretch that may have occurred during bursting. Chapter 9 presents in more detail the PE pipe joining procedures.

In most pipe bursting applications, the sewer line is old and deteriorated and so are the manholes along the line. It is economical on the long run in most cases to replace the old deteriorated manholes and use their location as pulling or insertion shafts. When existing manholes are replaced with new ones, connections to PE pipe can be made using flexible rubber manhole connectors called boots. A pipe clamp is used to tighten the boot around the PE pipe as shown in Figure 14.

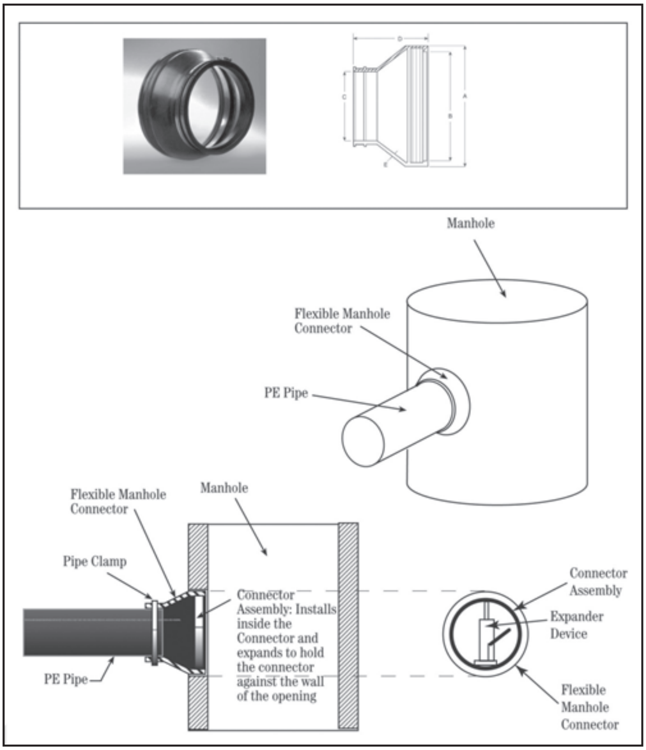

Figure 14 Connecting PE Pipe to New Concrete Manhole

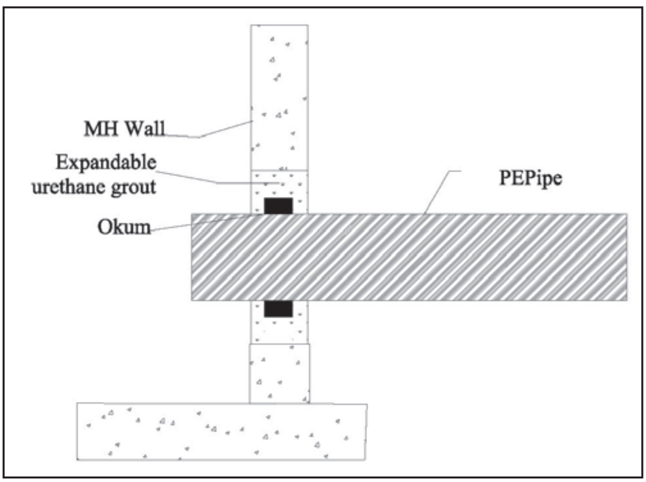

Figure 15 Connecting PE Pipe to Old Manhole

If the old manhole is in reasonable conditions and it is economical to use it after bursting, the manhole benching is removed and the pipe opening is enlarged to allow the passage of the bursting head. Expandable urethane grout and oakum can be used to create a seal between the exiting pipe opening and the PE pipe as shown in Figure 15. The compression allows pipe movement.

Frequently, when pipe bursting the inlets and outlets of the manhole are damaged, the resulting inlet or outlet is no longer round. A low shrink polymer cement grout is used to repair the damage. To get a good seal to the PE pipe, special PVC fitting with bell end and sand adhered to the outer surface (as shown in Figure 16) is used. The grout bonds to the manhole and the rough sandy surface of the PVC fitting giving a good seal. The gasket between the PVC fitting and the PE pipe allows the PE pipe to move if expansion or contraction occurs. The PVC fitting requires PE pipes with SDR of 21 or lower.

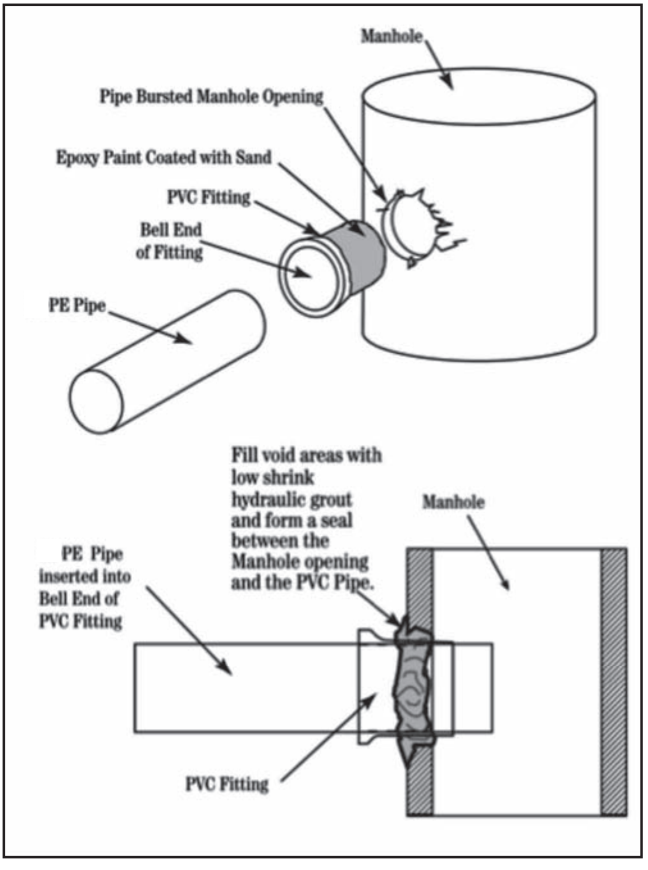

Figure 16 Connecting PE Pipe toOld Manhole with Damaged Inlets/Outlet

Pipe Connection to Other Pipes

PE pipes are joined to other PE fittings by heat fusion or mechanical fittings. They are joined to other material by means of compression fittings, flanges, or other qualified transition fittings (PPI).

Pipe Bursting Water Mains

The most common materials for existing water mains are cast iron, ductile iron, and PVC. All three can be replaced by pipe bursting but each requires a different piping burst approach. Cast iron pipe is a relatively brittle material, and therefore, basic pipe bursting system is sufficient. PVC pipes require multi-blade cutting accessories in front of the bursting head to facilitate cutting the pipe. Ductile iron pipe is not brittle; therefore, pipe splitting is the most suitable bursting system.

Valves are connected to PE pipe using mechanical joint (MJ) adapters, which is butt fused to the PE pipe. A gland ring is then used to make a restrained connection to ductile iron valves. Figure 17 shows connections to PVC or ductile iron pipes can be made using a female MJ connector, which is butt fused to the PE pipe. This connection provides a restrained connection.

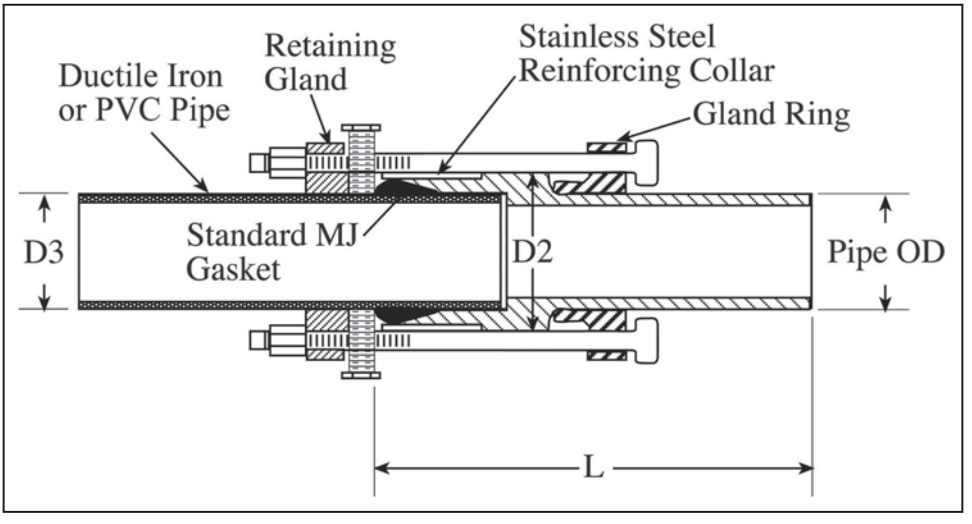

Figure 17 Connection to Existing PVC or DI Pipes Using Female MJ Adapter

Service connections can be attached to PE pipe using mechanical saddle connections or electrofusion saddles. Figure 18 shows an electrofusion saddle with a cutter attached; it is easy to hot tap PE pipe lines.

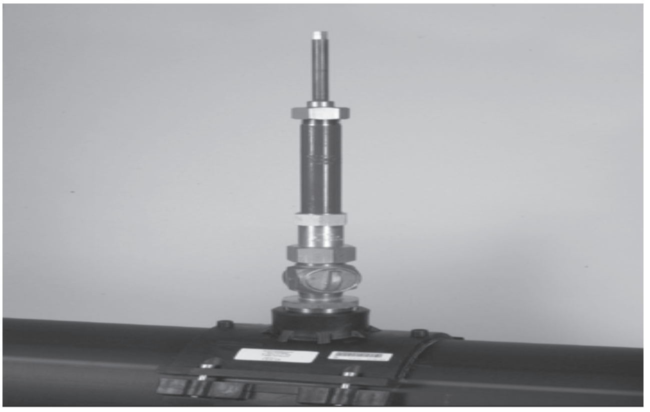

Figure 18 Electrofusion Saddle with a Cutter Attached

During installation, a temporary above ground PE pass is installed to continue to supply water to the home owners while the main line is under construction. Figure 19 shows an example of above ground PE bypass pipe.

The PE pipe can be pre-chlorinated prior to bursting to reduce the overall installation time and inconvenience to the home/business owners.

Figure 19 Example of Above Ground PE Bypass Pipe

Service Connections

The lateral connections and material plan stated in the submittal list should explain the proposed material and connection procedures. Video inspection of the original sewer line normally provides the location of service connections. In replacing water and gas lines, metal detectors can be used. Standard practice is to locate and expose services prior to pipe bursting. Service connections can be made with Inserta Tee®, specially designed fusion fittings, or strap-on saddles.

Figure 20 Inserta Tee® Fittings for Sewer Lateral Connections

For sewer applications, after service connections are excavated, a "window" is cut in the PE pipe wall, and then one of the above fittings connects the new PE pipe to the lateral connection. Inserta Tee® connection is a three piece service connection consisting of a PVC hub, rubber sleeve, and stainless steel band as shown in Figure 20. Inserta Tee® is compression fit into the cored wall of a mainline and requires no special tooling. Inserta Tees® are designed to connect 4 inch through 15 inch services to all known solid wall, profile, closed profile, and corrugated pipe. The PE lateral connection options are fusing a lateral PE pipe to the main line and Electrofusion sewer saddle. Fusing a lateral PE to the main PE line requires curved iron that allows heating the ends of both pipes. This connection require highly skilled fusion worker because it is usually made in small muddy space. Electrofusion saddle is mounted on the opening for fusion with the main line as shown in Figure 21. Careful considerations are needed to ensure that all exposed surfaces are cleaned and maintained in an acceptable condition for the fusion operation. Strap-on saddles use a PE or PVC saddle that are lined with a rubber layer; the saddle is trapped around the main line using a stainless steel strap as shown in Figure 21. After testing and inspecting the line and the connection, the excavation is backfilled and line returns to service. More service connections details for gravity and pressure applications are presented in Chapter 9 in this Handbook.

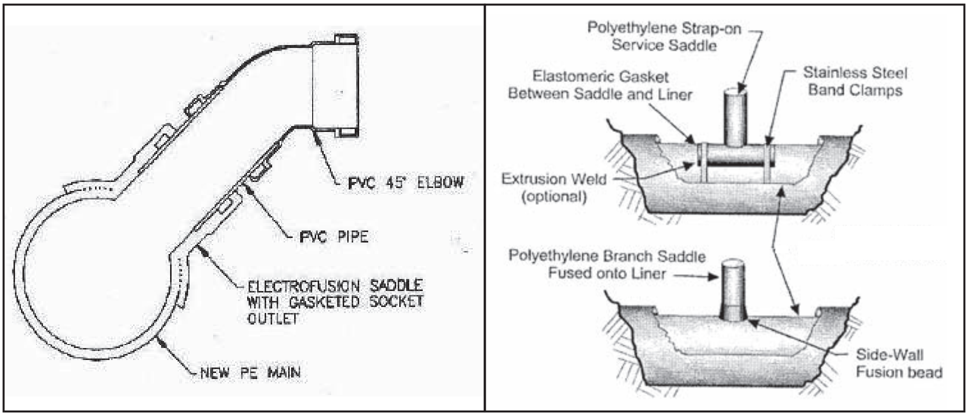

Figure 21 Pipe Fusion and Strap On Saddle Lateral Connections

Groves on the Outside Surface of the Pipe

One common misconception about bursting is that the existing pipe fragments from the old pipe can damage PE pipe during bursting. British Gas conducted study on bursting cast iron pipes and concluded that there was no damage to the PE. The pipe bursting research conducted at Louisiana Tech University and Bowling Green State University indicated the groves are very shallow and narrow when bursting clay, asbestos, and concrete pipes. The widest grove was 0.07 inch and depth of the deepest grove was 0.03 inch with no damage to the PE. CI, clay, concrete, and asbestos pipes generally break off without sharp shards that do not puncture PE (Atalah 1998 and 2004). The exception to this rule occurs when trying to significantly upsize ductile iron (DI) pipe. It is recommended to limit PE pipe to size-on-size bursting or a single upsize when bursting DI pipes. If larger upsize of DI pipe is required, PE pipes with harder outside shell similar to ones shown in Figure 22 can be used. If the PE will be dragged for a long distance over rough pavement, the contractor can reduce the risk of scratching the pipe by placing it on cut-outs of old PE or PVC to keep the pipe higher than the pavement. Sometimes the contractor needs to press on the PE with bucket of the excavator to ensure that the PE pipe is aligned with the old pipe at the entry point in the insertion shaft because the shaft is not long enough. Welding wheels similar to the one shown in Figure 23 reduces the risk of groves or scratches on the PE pipe. When the head end of the pipe reaches the pulling shaft, the pipe should be inspected for surface damage. Surface scratches or defects in excess of 10% of the wall thickness should be rejected.

As-Built Drawing

As built drawings are usually required for any underground utility construction as well as pipe bursting projects. The bursting contractor should mark the new line, manholes, ancillary structure information on a copy of the plans marked as and dedicated to the as-built. On these plans, the contractor should document any changes to the original layout of the underground utilities and structures that took place during the construction phase. For example, rerouting any utility due to the excavation of the shafts, reconfiguration of other utilities needed for bypass pumping, etc. should be marked on the as-built drawings. These changes shown on the as-built drawings should be verified and used to update the as-built electronic files for the locality.

Figure 22 Protecting the PE Pipe from Shards

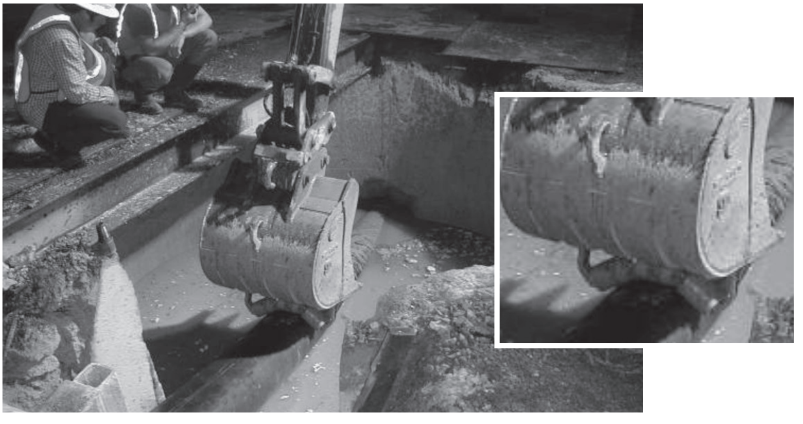

Figure 23 Protecting the PE Pipe from Groves Using Welded Wheels on the Bucket

Contingency Plan

An important submittal is the contractor's contingency plan. Most contractors have contingency plans that include planned corrective actions if certain events take place. Pipe bursting projects require adding a few specific additions to this standard contingency plan. Some of these specific events that are unique to pipe bursting and need to be addressed include:

- There is more than allowable ground movement or vibration
- The bursting progress is slow or the bursting head is stuck
- Problem with the bypass system and with diverting and reconnecting the services to the customers
- Damage to existing waterline, gas line, sewer line, power cable
- Dewatering problem in the insertion or pulling shaft or at lateral connection pits.

Safety Considerations

The standard safety procedures, adhered to in typical open cut construction, should be followed in bursting projects. Additionally, the workers should understand the components of the bursting system and how they work with special attention to the moving parts in the system. The involved workers should be trained on and equipped with the needed tools for confined space entry because the workers work in live sewers during flow bypass and diversion, which takes place mostly inside a manhole. The winch should thrusts against a thrust block that (along with the soil behind it) should withstand the forces of the winch. The stability of the soil behind the thrust block should not be compromised. During the flow bypass, the upstream pipe will be plugged; these plugs should be braced and preferably remotely inflated and deflated. Prior to bursting, the contractor has to ensure that there is no unforeseen gas line or power line close to bursting head.

Cost Estimating

Estimating pipe bursting projects for bidding purposes needs to be detailed, methodical, and systematic as it is the case for open cut installations. For each run, the contractor has to estimate the labor, material, and equipment needed for excavation and shoring of shafts, shaft bottom stabilization (concrete or gravel), bursting system set up, pipe fusion, lateral connection excavation, bypass pumping, bursting, service reconnection, shaft backfill, surface restoration, and potential dewatering.

As shown in Figure 7, the cost per foot of pipe bursting installations are less than that of open cut in unfavorable situations. The figure also shows that that cost is less than that of open cut in favorable conditions if the depth of cut is more than 10 feet.

Bennett and Ariaratnam (2005) presented Table 4 which shows the unit cost from several pipe bursting projects with different sizes and upsize percentages in North America.

TABLE 4
Example Unit Cost from Various Pipe Bursting Projects

Project #	Existing to New Pipe Information	Length	Overall Cost/LF
1	6” VCP to 8” PE	8,500 LF	$80
2	8” conc. to 12” PE	350 LF	$200
3	8” conc. to 14” PE	700LF	$215
4	10” PVC to 16” PE	520 LF	$230
5	12” AC Pipe to 14” PE	2640 LF	$160
6	24” RCP to 24” VCP	521 LF	$380

In 1999, the Trenchless Technology Center surveyed several municipalities and contractors for bidding prices per linear foot. The bid prices ranges for size to size replacement using pipe bursting for different pipe diameters are shown in Figure 24. The bid prices ranges for upsizing less than 20% and upsizing larger than 20% using pipe bursting replacement of different diameters pipes are shown in Figure 25 (Simicevic and Sterling, 2001).

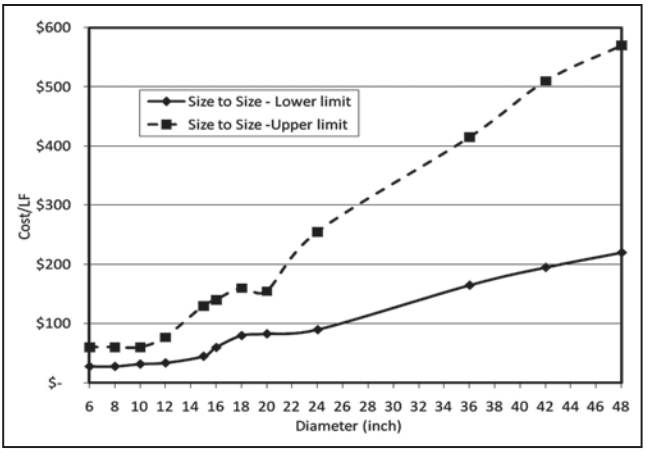

Figure 24 The Bid Prices Ranges for Size to Size Replacement for Different Pipe Diameters

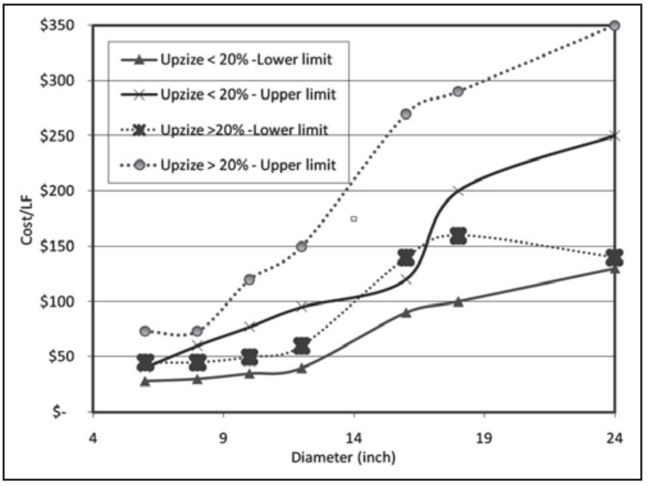

Figure 25 The Bid Price Ranges for Upsizing Less than 20% and Upsizing Larger than 20% Using Pipe Bursting Replacement of Different Diameter Pipes

Potential Problems and their Possible Solutions

The best option for dealing with the pipe bursting problems is avoiding them or reducing the probability of their occurrence by properly following the design and construction precautions mentioned thus far in this chapter. However, if some of these precautions are not followed or unforeseen conditions occur, this section attempts to provide actions that help avoid these troubles or correct them when they occur. Some of the potential problems associated with pipe bursting include sag correction, soil displacement, protecting utilities, bursting system selection problems, unforeseen obstacles, and site restrictions.

If the sewer line has excessive sags in it, these sags have to be repaired prior to bursting using any of the earlier – discussed techniques. However, if they were discovered after bursting, the contractor can fix the sag by digging this spot and improving the soil under the pipe. Replacement of a section of pipe may be needed at this excavation. If the excavation at this spot is not feasible, grouting and stabilizing the soil underneath the pipe can be a solution.

If excessive ground movement is anticipated very close to an existing structure, a ground movements and vibrations monitoring plan should be developed. If dangerous movements are observed, slowing the rate of bursting is mandated. If the movement is still high, bursting should be halted until analysis of the causes and corrective options is studied (including the option of abandoning the pipe bursting method). If there is a gas line, water line, or sewer line that is too close to the bursting head and is at risk of damage, exposing the line reduces this risk significantly. The excavation to expose this utility should be done using means that do not damage the line such as vacuum or manual excavation. If the pipe is shallow and there is a high risk of damaging the surface pavement, saw cutting the pavement prior to bursting prevents the spreading of the damage to the rest of the pavement. Later on, the pavement over the trench can be replaced.

If the bursting is significantly slower than expected, the contractor should investigate the reason and study the available corrective actions. Here some potential reasons for slow bursting:

The bursting system does not have sufficient power relative to the bursting applications (upsize percentage, large diameter, length, etc.). If this problem takes place shortly after the start of the run, the solution is replacing the system with a more powerful one. If it takes place close to the pulling shaft, continue until the bursting head reach the pulling shaft and replace the system before the next run if the reason of the slow down is not a repair ductile clamp or a fitting. Also in this case, consider shorting the length of the runs. If this problem takes place in the middle of the run at location where excavation is feasible, dig shaft on top of the bursting head and replace the system. The new shaft can be an insertion shaft for the remainder of the run.

Certain components or accessories of the system (for example, the winch, air compressor, hydraulic components, cutting accessories in front of bursting head, etc) are under sized or unmatched. Adding accessories in front of the bursting head to cut PVC fitting, ductile clamps or fittings, etc. reduces the potential of stopping or slowing the bursting. Upsizing these components (within the allowable range of that system) is the recommended solution. Matching the system and its components and accessories with the needs of the bursting jobs may solve the problem.

There are obstacles such as ductile repair fittings, concrete encasement, or change in the existing pipe material along the line. If the obstacle is close to the pulling shaft, continue bursting slowly until the head reaches the pulling shaft. If the obstacle is far from the pulling shaft, rescue shaft to remove the obstacle, change the bursting head, or add/change cutting accessories.

The soil around the pipe is flowing or running and is causing excessive friction. Lubrication of outside surface of the pipe with suitable lubricant is an effective way to reduce required pulling force on the PE pipe by reducing the friction between the pipe and the soil. The key to apply this solution is setting a lubrication manifold and lubrication line before bursting start to pump the lubrication during bursting.

Breaking the old pipe in running soil below the GWT fills the pipe with dirt so that the operation turns from bursting to piercing. The first step is to make sure that bursting head did not damage any nearby water line then dewater the site.

It is critical that the contractor ensure that the replacement pipe meets the specification before, during, and after bursting. Adhering to the quality control and quality assurance plans during the manufacturing and shipping to the site along with proper unloading of the pipe reduces risk of pipe failure. It is recommended that the pipe fusion is performed by certified and well trained workers under appropriate supervision to reduce the risk of pipe failure later when repair is difficult and costly. For pressure application, the PE pipe should be inspected and pressure tested before bursting.

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Credit

This chapter was prepared by Dr. Alan Atalah, PE, Associate Professor and Graduate Coordinator, Bowling Green State University, Ohio, USA.