Guidelines for Pipe Bursting

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Jadranka Simicevic
Raymond L. Sterling

Prepared for:

U.S. Army Corps of Engineers

Engineering Research and Development Center (ERDC)

3909 Halls Ferry Road

Vicksburg, MS 39180

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Preface

Although pipe bursting is an established and widely used trenchless method for renewal of gas, water and sewer pipelines, it is not covered adequately with guidelines and standards. The need for guidelines in this area was demonstrated in a study *Identification of Needs for User Guidance in Trenchless Technology Applicatiosn*, which was prepared by the Waterways Experiment Station (WES) (now Engineering Research and Development Center - ERDC) with the assistance of the Trenchless Technology Center (TTC) in 1998. The study surveyed existing guidelines and standards, as well as those under development by various organizations in the USA and abroad, and identified pipe bursting, pipe ramming and impact moling as areas of trenchless technology with priority needs for guidance development.

These guidelines have been prepared to assist owners, designers and contractors involved in pipeline renewal/rehabilitation projects to evaluate capabilities of existing trenchless pipe replacement methods for such projects. The guidelines are most applicable to the pipe bursting systems: pneumatic, hydraulic expansion and static pull systems, and to pipe implosion. They also have some relevance to allied trenchless pipe replacement techniques but these are not necessarily addressed directly: pipe splitting, pipe eating, pipe reaming and pipe ejection.

The guidelines are based on information obtained from technical papers, research reports, manufacturers' literature, and other related information, and from comments and reviews made by industry experts. The following industry representatives are especially thanked for their reviews and advice:

- Mr. William Sims, City of Nanaimo, British Columbia, Canada
- Mr. Herbert K. Quigley, Vermeer/Earth Tool Co., Oconomowoc, WI
- Mr. John Nowak, Nowak Pipe Reaming Inc., Goddard, KS
- Mr. William Putnam, Jabar Corporation, Calhoun, LA

A significant contribution to the preparation of the guidelines was a research project on the effect of pipe bursting on nearby utilities, pavement and structures conducted by the Trenchless Technology Center (TTC) in 1996-97 (Atalah 1998). This research was supported by the State of Louisiana, with substantial funding and support from the pipe bursting industry.

Executive Summary

Pipe bursting is a well-established method for trenchless replacement of worn out and undersized gas, water and sewer pipes. An existing pipe is replaced size-for-size or up-sized with a new pipe in the same location. The technique is the most cost effective when there are few lateral connections, when the old pipe is structurally deteriorated, and when additional capacity is needed.

Pipe bursting, which can be either pneumatic, hydraulic expansion or static pull, fractures a pipe and displaces the fragments outwards while a new pipe is drawn in to replace the old pipe. In addition to pipe bursting there are several other methods for trenchless pipe replacement, which differ in the way the old pipe is fractured and the fragments displaced. Pipe implosion fractures the pipe inwards prior to the outward displacement of the pipe fragments. Pipe splitting splits open existing ductile pipes. Specially designed variations of the microtunneling system and of the reaming process from horizontal directional drilling are used in pipe eating and pipe reaming to excavate the old pipe in fragments. Both methods remove the fragments to the surface through circulating slurry rather than displacing them. Pipe ejection jacks out the old pipe towards a receiving pit (manhole) where it is broken up and removed while the new pipe is being inserted.

Typical pipe bursting involves the insertion of a conically shaped tool (bursting head) into the old pipe. The head fractures the old pipe and forces its fragments into the surrounding soil. At the same time, a new pipe is pulled or pushed in behind the bursting head. The base of bursting head is larger than the inside diameter of the old pipe to cause the fracturing and slightly larger than the outside diameter of the new pipe, to reduce friction on the new pipe and to provide space for maneuvering the pipe. The rear of the bursting head is connected to the new pipe, while its front end is connected to a cable or pulling rod. The bursting head and the new pipe are launched from the insertion pit, and the cable or pulling rod is pulled from the reception pit. The cable/rod pull together with the shape of the bursting head keeps the head following the existing pipe, and specially designed heads can help to reduce the effects of existing sags or misalignment on the new pipeline.

The size of the pipe currently being replaced by pipe bursting typically ranges from 2 inches to 36 inches, although the bursting of larger diameters is increasing (pipes up to 48 inches diameter have been replaced). Theoretically there is not a limit in size of pipe to be burst. The limit depends on the cost effectiveness compared to conventional replacement, on the local ground conditions as to the potential for ground movement and vibration, and the ability to provide sufficient energy to break the existing pipe while simultaneously pulling in a new pipe.

Pipe bursting is typically carried out in 300 to 400 feet lengths, which corresponds to a typical distance between sewer manholes. However, much longer runs have been replaced. Pipes suitable for pipe bursting are typically made of brittle materials, such as vitrified clay, cast iron, plain concrete, asbestos, or some plastics. Reinforced concrete pipe (RCP) can also be successfully replaced if it is not heavily reinforced or if it is substantially deteriorated. Ductile iron and steel pipes are not suitable for pipe bursting, and can only be replaced with pipe splitting.

Pipe bursting has limitations. Difficulty can arise in expansive soils, close proximity of other service lines, point repairs that reinforce the existing pipe with ductile material, a collapsed pipe at a certain point along the pipe, etc.

Pipe bursting operation creates outward ground displacements adjacent to the pipe alignment. The ground displacements tend to be localized, however, and to dissipate rapidly away from the bursting operation. The bursting operation can cause ground heave or settlement above or at some distance from the pipe alignment. The most critical conditions for ground displacement are when: the pipe to be burst is shallow and ground displacements are primarily directed upward, significant upsizing percentages for large diameter pipes are used, and deteriorated existing utilities are present within 2-3 diameters of the pipe being replaced.

Typical pneumatic pipe bursting may create quite noticeable ground vibrations on the surface above the bursting operation. Still it is very unlikely to damage the existing nearby surface or underground structures, unless it is carried out at very close distances to them: the bursting head should not pass closer than 2.5 feet from buried pipes and 8 feet from sensitive surface structures. If distances are less than these, special measures should be taken to protect the existing structures, e.g. excavate the crossing point to relieve stress on the existing pipe.

The most favorable ground conditions for pipe bursting are soils that can be moderately compacted (reducing the lateral extent of outward ground movements), in which the expanded hole behind the bursting head does not cave in before the replacement pipe is installed (lowering the drag and the tensile stresses in the pipe during installation). Less favorable ground conditions involve densely compacted soils and backfills, soils below the water table and dilatant soils. Each of these soil conditions tends to increase the force required for the bursting operation and to increase the zone of influence of the ground movements. Special soils such as highly expansive soils or collapsible soils will also cause problems. For most soil conditions, it is simply necessary to provide the required power to effect the burst, displace the soil and pull the replacement pipe in over the length of the burst and to consider the potential effect of the ground displacements and vibrations on adjacent utilities and structures. Longer bursts can be accomplished more easily in favorable ground conditions. When the soil provides a high friction drag on the pipe and the length of run is long enough to generate high tensile forces on the replacement pipe, bentonite or polymer lubrication muds may be injected into the annular space behind the bursting head to help keep the hole open and to reduce the frictional drag on the replacement pipe.

HDPE and MDPE are the most common replacement pipe materials. Other types of replacement pipe used in pipe bursting include cast iron pipe, vitrified clay pipe, and reinforced concrete pipe.

1. Introduction

Pipe bursting and related techniques are well-established methods for trenchless replacement of worn out and undersized gas, water or sewer pipelines. They can offer significant potential savings and drastically reduced surface disruption to public and private utility owners under favorable conditions. The methods result in an existing pipe being replaced size-for-size or up-sized with a new pipe in the same location. The techniques are most advantageous in cost terms (1) when there are few lateral connections to be reconnected within a replacement section, (2) when the old pipe is structurally deteriorated, (3) when additional capacity is needed, and (4) when restoration/environmental mitigation requirements are onerous.

The following are the techniques of trenchless pipe replacement which currently exist:

- pipe bursting using pneumatic bursting, hydraulic expansion, or static pull – techniques that fracture the existing pipe, displace the fragments outwards, and pull a new pipe in to replace the old pipe (this technique is by far the most widely used trenchless pipe replacement method);
- pipe implosion – a technique that fractures the existing pipe inwards and displaces the pipe fragments outwards, and pulls a new pipe in to replace the old pipe;
- pipe splitting – a technique that splits open existing ductile pipes, and pulls a new pipe in to replace the old pipe;
- pipe eating – a technique that uses a specially-designed variation of a microtunneling machine, which excavates the old pipe in fragments and removes them rather than displaces them, and jacks the new pipe into the place as in a microtunneling operation;
- pipe reaming – a technique that uses a specially-designed variation of the reaming process from horizontal directional drilling, to excavate the existing pipe in fragments and remove them rather than displace them, and pulls a new pipe in to replace the old pipe;
- pipe ejection and pipe extraction – techniques that remove the existing pipe as whole from the ground, by pushing or pulling it towards a reception pit where it is broken up and removed, and simultaneously install a new pipe

1.1. General Description of Pipe Bursting

In a typical pipe bursting operation, a cone-shaped tool ("bursting head") is inserted into the existing pipe and forced through it, fracturing the pipe and pushing its fragments into the surrounding soil. At the same time, a new pipe is either pulled or pushed in the annulus left by the expanding operation (depending on the type of the new pipe). In the vast majority of pipe bursting operations, the new pipe is pulled into place. The new pipe can be of the same size or larger than the replaced pipe. The rear of the bursting head is connected to the new pipe, and the front end of the bursting head to either a winching cable or a pulling rod assembly[1]. The bursting head and the new pipe are launched from the insertion pit. The cable or rod assembly is pulled from the pulling or reception pit.

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[1] When multiple upsizes are required or when bursting in tough soil conditions, the pipe can also be attached to a rear mounted pipe puller. Alternatively, the tool can be equipped with a front mounted bursting head and a full body expander.

The leading or nose portion of the bursting head is often smaller in diameter than the existing pipe, to maintain alignment and to ensure a uniform burst. The base of the bursting head is larger than the inside diameter of the existing pipe to be burst, to fracture it. It is also slightly larger than the outside diameter of the replacement pipe, to reduce friction on the new pipe and to provide space for maneuvering the pipe. The bursting head can be additionally equipped with expanding crushing arms, sectional ribs, or sharp blades, to further promote the bursting efficacy.

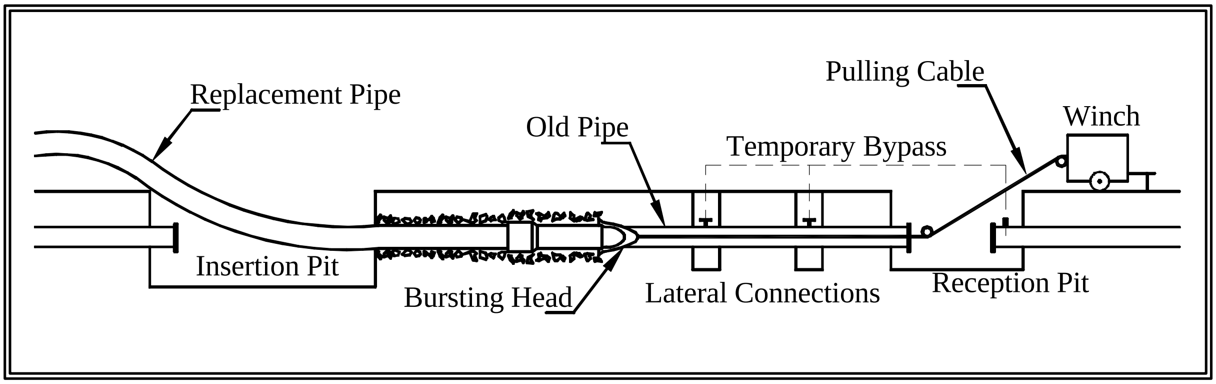

Figure 1-1: Typical pipe bursting operation layout

Sometimes an external protective sleeve pipe is installed during the bursting process and the product pipe installed within this casing or conduit pipe. This is normally only considered for pressure pipe installations. Alternately, in gravity sewer applications, the wall thickness of the product pipe is increased to allow for external scaring of the pipe as it is pulled into place.

The bursting operation can proceed either continuously or in steps, depending on the applied type of pipe bursting system. Before bursting, the existing pipe should always be cleaned so that any sand or debris is removed (the required pull force will be reduced), and the service connections located and disconnected.

1.2. Main Classes of Pipe Bursting

Currently available pipe bursting systems can be classified into three main classes: (1) pneumatic pipe bursting, (2) hydraulic expansion, and (3) static pull, which is based on the type of bursting head used. Pneumatic head uses pulsating air pressure to drive the head forward and burst the old pipe. A small pulling device guides the head via a constant tension winch and cable. Hydraulic head expands and closes sequentially as it is pulled through the pipe, bursting the pipe on its way. Static head has no moving internal parts. The head is simply pulled through the pipe by a heavy-duty pulling device via a segmented drill rod assembly or heavy anchor chain.

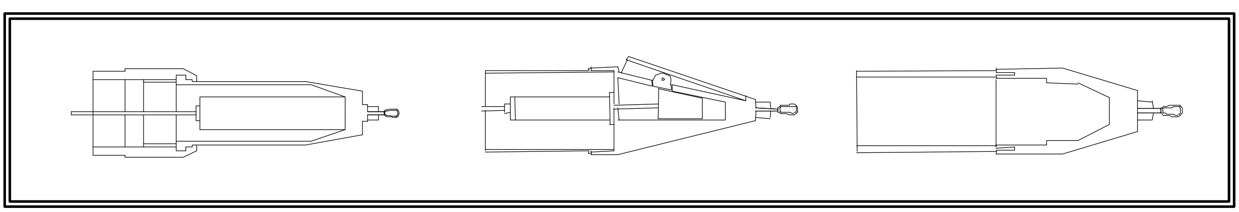

Figure 1-2: Pneumatic, hydraulic and static head

1.2.1. Pneumatic Pipe Bursting

Pneumatic pipe bursting is the most frequently used type of pipe bursting to date. It is used on the majority of pipe bursting projects worldwide (Howell 1995).

In the pneumatic pipe bursting, the bursting head is a cone-shaped soil displacement hammer. It is driven by compressed air, and operated at a rate of 180 to 580 blows /minute.

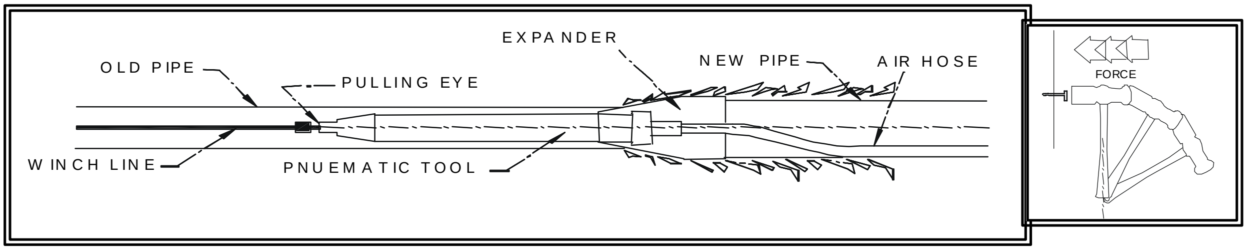

Figure 1-3: Bursting head of the pneumatic system

The percussive action of the bursting head is similar to hammering a nail into a wall, where each impact pushes the nail a small distance farther into the wall.

In a like manner, the bursting head creates a small fracture with every stroke, and thus continuously cracks and breaks the old pipe.

The percussive action of the bursting head is combined with the tension from the winch cable, which is inserted through the old pipe and attached to the front of the bursting head. It keeps the bursting head pressed against the existing pipe wall, and pulls the new pipe behind the head.

The air pressure required for the percussion is supplied from the air compressor through a hose, which is inserted through the new pipe and connected to the rear of the bursting tool. The air compressor and the winch are kept at constant pressure and tension values respectively. The bursting process continues with little operator intervention, until the bursting head comes to the reception pit.

1.2.2. Hydraulic Expansion

In the hydraulic expansion system, the bursting process advances from the insertion pit to the reception (pulling) pit in sequences, which are repeated until the full length of the existing pipe is replaced. In each sequence, one segment of the pipe (which matches the length of the bursting head) is burst in two steps: first the bursting head is pulled into the old pipe for the length of the segment, then the head is expanded laterally to break the pipe (Topf 1991, 1992, Tucker et al. 1987).

The bursting head is pulled forward with a winch cable, which is inserted through the old pipe from the reception pit, and attached to the front of the bursting head. The rear of the bursting head is connected to the replacement pipe and also the hydraulic supply lines are inserted through the replacement pipe. The bursting head consists of four or more interlocking segments, which are hinged at the ends and at the middle. An axially mounted hydraulic piston drives the lateral expansion and contraction of the head.

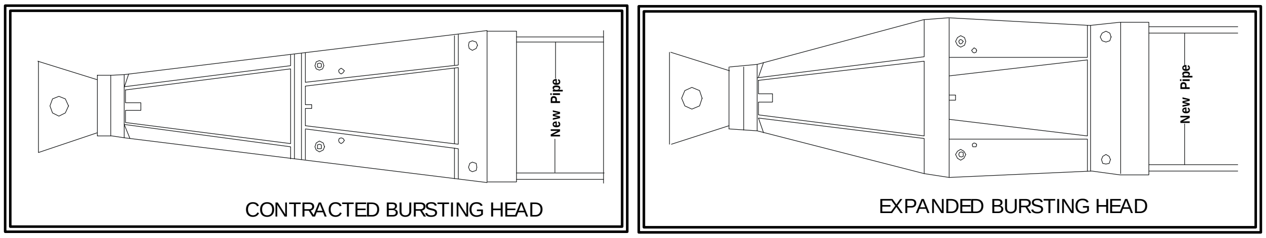

Figure 1-4: Hydraulic bursting head (Xpandit) in expanded and contracted positions

1.2.3. Static Pull

In the static pull system, the force for breaking of the existing pipe comes only from pulling the bursting head forward. The head is pulled by either a pulling rod assembly (TRS system) or a winch cable, which is inserted through the existing pipe and attached to the front of the bursting head. The tensile force applied to the bursting head is significant. The cone-shaped bursting head transfers this horizontal pulling force into a radial force, which breaks the old pipe and provides a space for the new pipe.

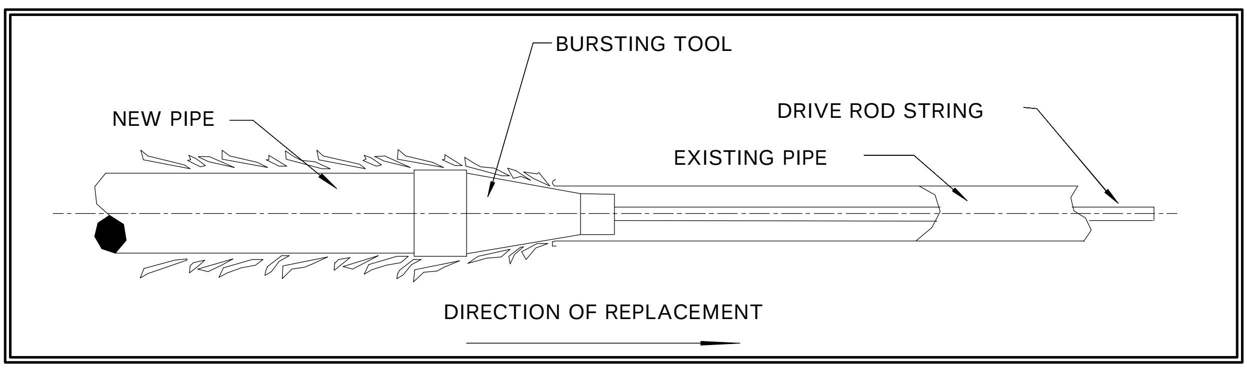

Figure 1-5: Bursting head of the static pull system

If a rod assembly is used for pulling, the bursting process is done in consecutive sequences, rather than continuously. Prior to bursting, the segmented rods are inserted into the old pipe from the reception pit. The rods are only a few feet long, and during insertion they are threaded together to reach the bursting head at the insertion pit. There, they are attached to the front end of the bursting head, and the new pipe is connected to its rear end. In each sequence during the bursting, the hydraulic unit in the reception pit pulls the rods for the length of individual rods, and the rods are separated from the rest of rod assembly as they reach the reception pit.

If a winch cable is used instead of rods, the pulling process can be continuous. However, a typical cable system does not transmit as a large pulling force to the bursting head as a rod assembly.

1.3. Other Pipe Replacement Systems

1.3.1. "Implosion" (Pipe Crushing)

In the "implosion" system, the bursting tool consists of two parts: a crushing head, which breaks the existing pipe and forces the pipe fragments inwards into the pipe void, and a steel cone, which pushes the crushed pipe fragments and soil outwards, making room for the new pipe.

The crushing head is cylinder-shaped, and slightly larger than the existing pipe. Inside the cylinder, there are steel blades, which extend radially from the center and fracture the old pipe, as the head is pulled forward. The pulling is done with a rod assembly, as in the static pull system.

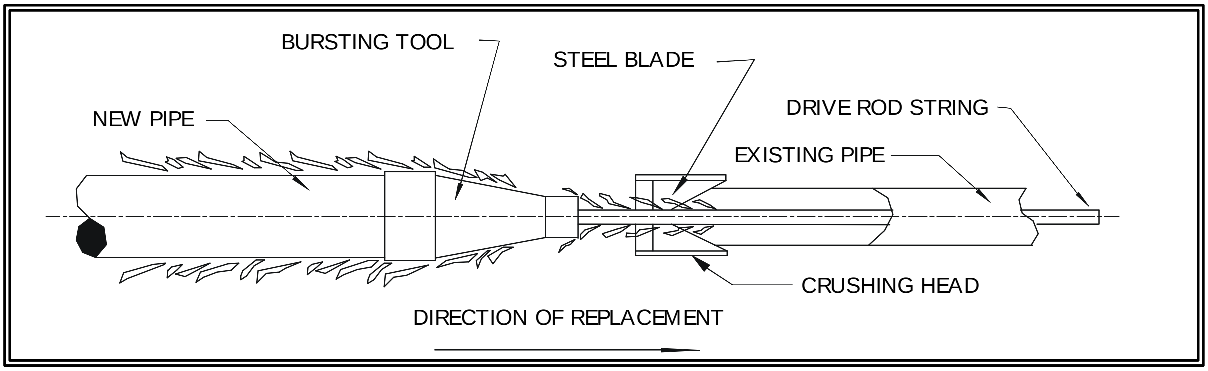

Figure 1-6: The crushing head in implosion (IMPIPE System)

1.3.2. Pipe Splitting

Pipe splitting system is used for pipes that are not brittle, like steel and ductile iron gas mains. Instead of the bursting head, the system uses a splitter, which cuts the existing pipe along one line on the bottom and opens it out, rather than fracturing it. The splitter is pulled through the existing pipe by either a wire rope or steel rods. It consists of one or more of three parts: (1) a pair of rotary slitter wheels, which make the first cut, (2) a hardened sail blade on the underside of the splitter, which follows, and (3) an expander, whose conical shape and off-centered alignment force the split pipe to expand and unwrap.

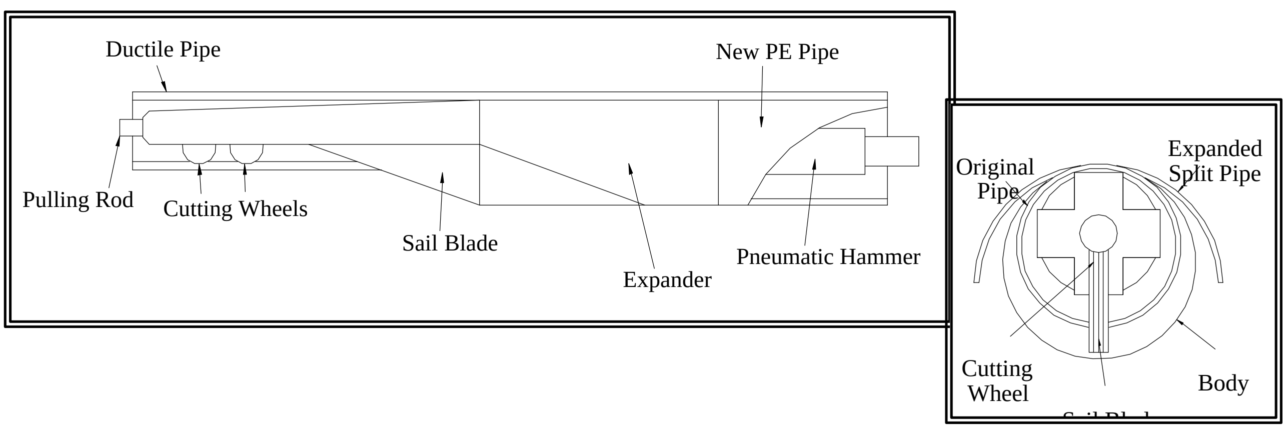

Figure 1-7: Pipe splitting system and section view of the pipe splitting system (ConSplit)

The unwrapping of the pipe is smooth, without generating hoop stresses or longitudinal bending in the pipe walls, that could cause high pulling forces and jamming. The splitting and unwrapping of the existing pipe creates a hole immediately behind the splitter large enough to allow the new pipe to be pulled in. The old pipe dislocates to a position above the hole and the replacement pipe, thus protecting the new pipe from damage.

1.3.3. Pipe Eating

Pipe eating is a modified microtunneling system specially adapted for pipe replacement. The existing defective pipeline is crushed and removed through the new pipeline by the circulating slurry system. A new pipe is simultaneously installed by jacking it behind the microtunneling machine. The new pipe may follow the line of the old pipe on the entire length, or may cross the elevation of the old pipe on a limited segment only. The system is remotely controlled and guided with a surveyed laser line from the drive pit, and prepared to "eat" whatever is in the way, the old pipe or the ground only.

The system has a cutting head and a shield section. The cutting head has cutting teeth and rollers that cut the pipe, and cutting arrangements close to the edge of the shield that cut the ground to the required diameter to take the new pipe. The cutting head is cone-shaped, which puts the material of the old pipe into tension and thus reduces the heavy wear of cutting teeth. The shield section carries the cutting head and its hydraulic motor system. The head and shield are launched from a drive pit, where a thrust frame is located. It provides a thrust that is applied on the cutting head through the new pipe to push the head and shield forward through the ground.

1.3.4. Pipe Reaming

Pipe reaming is a modified back reaming method used in directional drilling, which is specially adapted for pipe replacement. First, the pilot drill string is inserted through the existing pipe. Next, a specially designed reaming tool is attached to the drill string and pulled back through the pipe, while simultaneously installing the new pipe. The reamer has cutting teeth, which grind and pulverize the existing pipe through a “cut and flow” process, rather than a compaction. The pipe fragments and the excess material from upsizing are carried with the drilling fluid to manholes or reception pits, and retrieved with a vacuum truck or slurry pump for disposal.

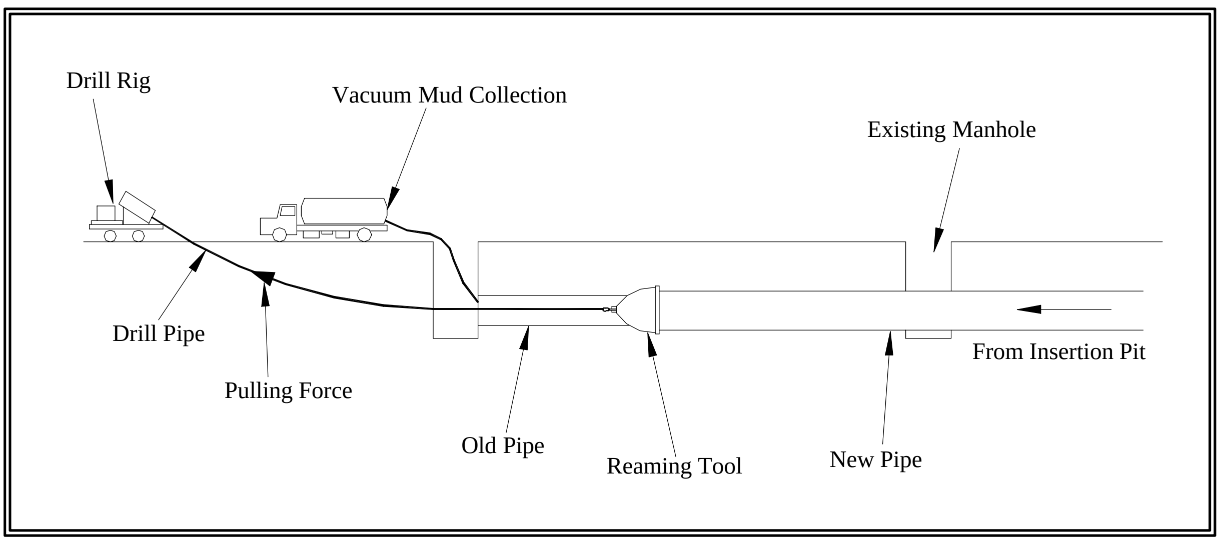

Figure 1-8: Pipe reaming

1.3.5. Pipe Ejection/Extraction

Pipe ejection (modified pipe jacking) and pipe extraction (modified static pull) are pipe replacement systems, in which the unbroken existing pipe is removed from the ground, while the new pipe is simultaneously installed. The old pipe is broken into pieces only as it completely exits out of the ground. These techniques are applicable only for pipes with sufficient remaining thrust capacity to withstand the push or pull forces. They are used on shorter replacement sections to avoid high frictional resistance.

In pipe ejection, the replacement pipe pushes out the old pipe. A jacking frame is placed into the insertion pit, as well as the replacement pipe, which is installed in segments. The new pipe is placed against the old pipe, and as the new pipe is jacked, the old pipe is pushed toward a reception pit or manhole. At the reception pit, the existing pipe is broken into pieces and removed. The jacking frame and the insertion pit are sized to fit the length of individual pipe segments.

In pipe extraction, the replacement pipe is pulled in place of the old pipe. An extraction machine is placed into one pit, and the replacement pipe is fed from the other pit. A pulling device (a pulling rod assembly) is inserted through the existing pipe, and attached to the extraction machine on one end, and a tool assembly, which is connected to the replacement pipe, on the other end. The tool assembly consists of a centralizing device, pull plates, and a cylindrical expander or plug, which allows the system to handle both size-for-size replacement and upsizing.

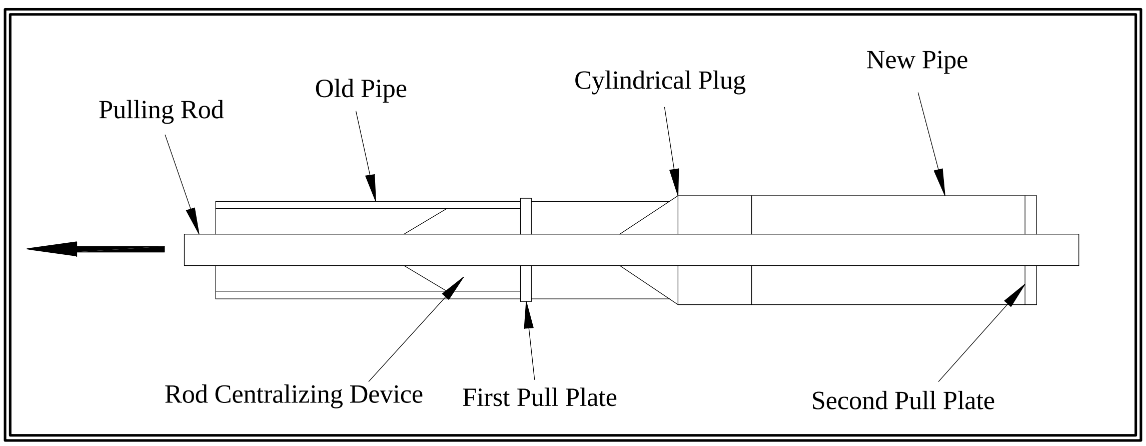

Figure 1-9: Pipe extraction

1.3.6. "CLG System"

CLG (Controlled Line and Grade) System is a pipe replacement method with ability to correct sags, humps or misalignments in existing pipelines. The system is new on the trenchless market, with patent still pending and limited field experience. A steel rod string that consists of short steel rods coupled together is inserted through the existing pipe, along its entire length. After the rod string is precisely aligned to the desired line and grade in insertion and reception pit and anchored in tension, a light cement slurry is pumped in to fill the pipeline and any open voids around it. Once the cement slurry is cured (between 4 to 24 hours), a bursting head and a replacement pipe are attached to one end of the rod string. The rod is then pulled out towing the new pipe behind it. A bentonite lubricant may be supplied to reduce the pulling force required for the operation.

As the bursting advances through the cured slurry, the bursting head encounters equal resistance from the cement/existing pipe/ground envelope at all points around its face and circumference. Because of that, the bursting head is not as likely to be deviated from its path and is less affected by sags, misalignments and undulations in the old sewer pipeline. The cured light cement provides the support and a shield against shards from the old burst pipe, rocks and harmful objects in the pipe zone.

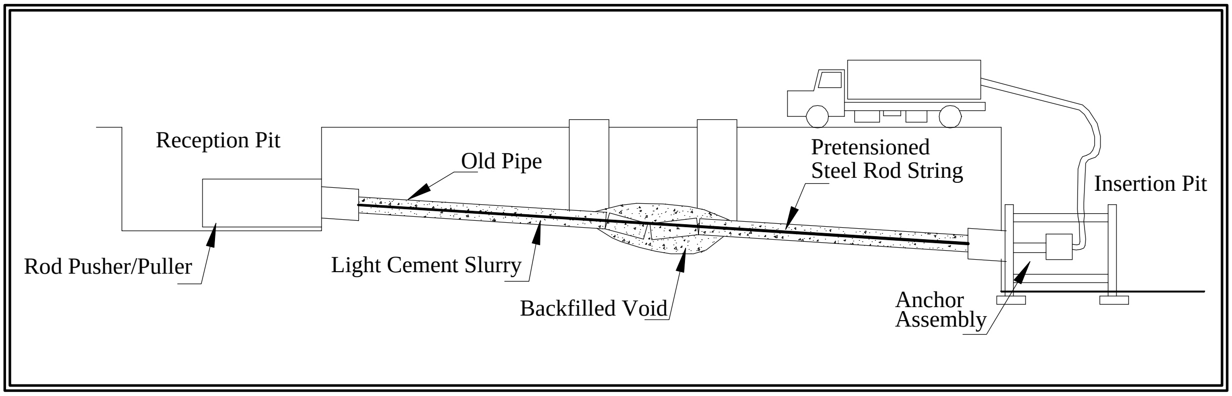

Figure 1-10: CLG system

The described method is modified under the following conditions:

- When larger pipes are being replaced (generally 15" and larger), a boring tool is substituted for the bursting head.
- If the existing pipe is deviated to the extent that a straight axis through the pipe lies partly outside the pipe, special rods equipped with cutting edges along their length are combined with standard rods to make a steel rod string. The rod string is positioned at correct line and grade in insertion and receiving pits, but is forced into a curved shape to accommodate line deviation. When the rod string is anchored in tension, rods with cutting edges press against the inside wall of the sewer pipe – under the crown in the case of sag. The rod string is then rotated, forcing the cutting edges to cut through the existing pipe wall and surrounding ground until the rod string is straightened out at the desired correct line and grade.

1.4. Applicability

1.4.1. Range of Applications

Pipe bursting can be applied on a wide range of pipe sizes and types, in a variety of soil and site conditions.

The size of pipes being burst typically ranges from 2 to 36 inches, although it can be even larger (a 48-inch has been replaced). It is expected that bursting of extremely large pipes (e.g., 80-inch) will also be possible with larger equipment in the future. The most common pipe bursting is size-for-size, or upsizing the diameter of the existing pipe up to three sizes (e.g. 8-inch to 12-inch). Large upsizings require more energy and cause more ground movement. They slow the replacement operation and need careful evaluation when large diameter existing pipes are upsized.

With respect to the type of existing pipe, the pipes suitable for pipe bursting are typically made of brittle materials, such as vitrified clay, cast iron, plain concrete, asbestos, or some plastics. Reinforced concrete pipe (RCP) can also be successfully replaced, if it is not heavily reinforced, or if it is substantially deteriorated. Ductile iron and steel pipes are not suitable for pipe bursting, but can be replaced using pipe splitting.

The bursting length is usually between 300 and 400 feet, which is a typical distance between sewer manholes. However, much longer bursts may be achieved when needed. A long burst generally requires more powerful equipment to complete the job. The longest continuous pipe reaming replacement was 1,320 ft (Nowak Pipe Reaming).

1.4.2. Unfavorable Conditions and Limitations

Unfavorable conditions for pipe bursting are (1) expansive soils (see chapter 3.1), (2) obstructions along the existing pipe length in form of completely collapsed pipe, (3) metallic point repairs[2] that reinforce the existing pipe with ductile material, (4) concrete envelopment[3] (see chapter 1.5.2), and (5) adjacent pipes or utility lines that are very close to the pipe being replaced. The obstructions do not necessarily prevent the pipe bursting, and the problem is usually solved with localized excavations.

Limitations in applicability come from either (1) economical aspect (its comparative costs versus cost of conventional replacement), (2) safety aspect (potential damage to the neighboring utilities and structures), or (3) technical aspect (the ability to provide sufficient energy to complete the operation).

1.5. Effect of Pipe Bursting on Surrounding Environment

1.5.1. Ground Displacements

Every bursting procedure is associated with ground displacements. Even when the replacement is carried out size-for-size, soil movements are created because the bursting head has a larger diameter than the replacement pipe. Ground movements are not exclusive to pipe bursting, and they can be significant in open trench replacements of pipes as well (Rogers 1995). This section explains the general behavior of the ground movements under particular site conditions, reveals what conditions can be of concern, and suggests some minimal requirements for pipe bursting operations.

The soil displacements expand from the source through the soil in the direction of the least soil resistance. They are a function of both time and space. The displacements are the greatest during the bursting operation, and they can partially diminish over time after the burst. They generally tend to be localized, and to dissipate rapidly with the distance from the source.

The ground displacements depend primarily on (1) degree of upsizing, (2) type and compaction level of the existing soil around the pipe, and (3) depth of bursting. Illustrations of the effect of site conditions on ground movements are shown in Figure 1.11.

In a relatively homogeneous soil with no close rigid boundaries, the displacements are likely to be directed upwards at smaller depths (A), while at increased depths they are expected to have more uniform direction (B). In relatively loose soils and for small diameter pipes, a uniform expansion is expected at a depth of 2 ft, whereas in relatively dense soils the expansion at this depth would still be predominately upwards (Chapman, 1996).

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[2] Metallic point repairs are considered the only real obstruction for pipe reaming. Concrete encasement need not be removed with this method, unless reinforced.

[3] The contractors often fill the excavated areas with low class concrete that is sometimes hard to burst through.

The soil conditions in a trench are usually non-homogenous. The backfill material is often weaker than the original surrounding soil and the displacements are likely to be mostly confined within the existing trench (C). If the existing trench or pipe bedding is weak the pipe may move downwards instead of upwards (D).

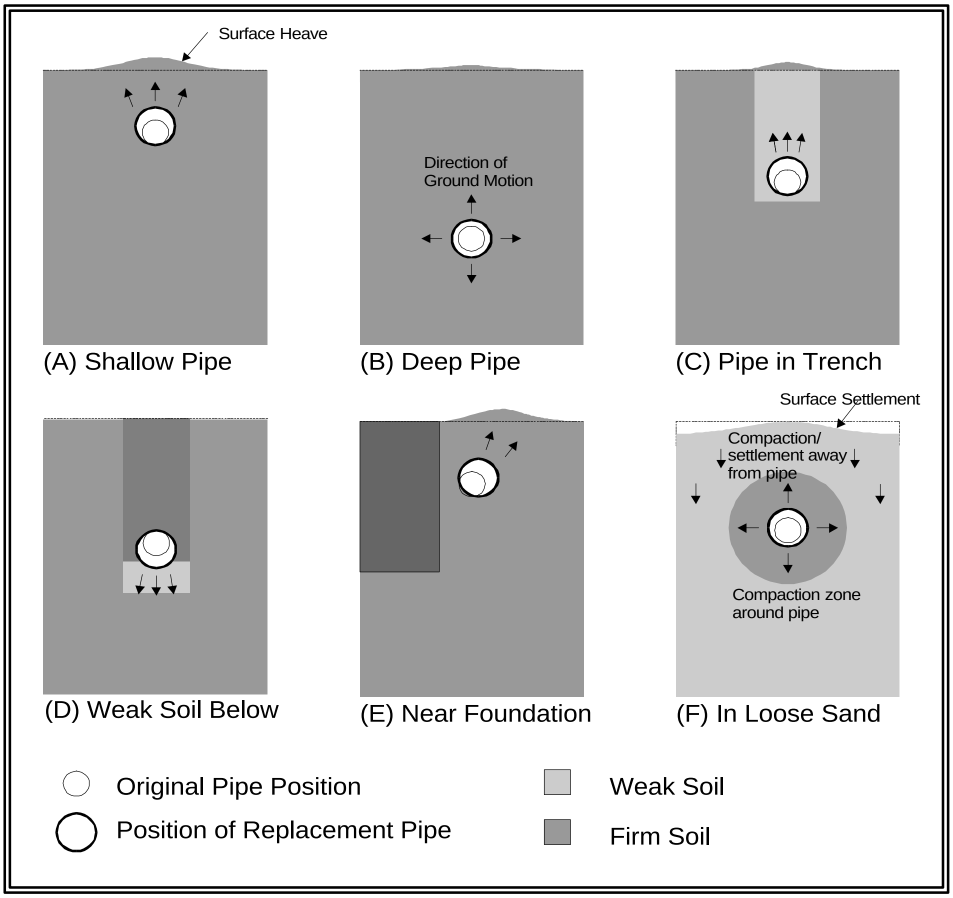

Figure 1-11: Conceptual effect of site conditions on ground displacements

If the ground movements are not attenuated before reaching the surface, they cause either surface heave or settlement. The ground movements generally tend to spread symmetrically around the vertical axis through the existing pipe, and heave or settlement is usually expected directly above the pipe. However, there are exceptions. Proximity of a rigid boundary may break the vertical symmetry and shift the surface heave to the side (E). Also, surface heave and settlement may sometimes both be present. This is the case when the pipe is upsized in a loose soil that will be compacted by ground vibrations. The diameter increase is compensated by soil compaction within a short distance of the pipe (F), and outside of that zone settlement may occur.

It is a combination of many factors that determines whether the surface will heave or settle. If the existing soil is loose sand or relatively new trench backfill which is still settling, the bursting process can act to further settle the existing soil. Otherwise, if the soil is well compacted and the pipe not very deep, the bursting process is likely to create a surface heave, especially when significantly upsizing the existing pipe.

The soil displacement profiles tend to be more predictable in cohesive soils. In sands, the tail void (annular space) created by the bursting head can easily collapse locally.

The most critical conditions for the occurrence of considerable ground displacements (Atalah, 1998) are when (1) the existing pipe is not deep and the ground displacements are directed upwards; (2) already large diameter pipes are significantly upsized; (3) there are deteriorated existing utilities within 2-3 diameters of the existing pipe.

As discussed in the section about effect on nearby utilities, the ground displacements should be acceptable if the bursting is performed under a certain minimum depth of cover and at certain distance from adjacent buried utilities (Hrabosky, 1999).

1.5.2. Positioning of the Replacement Pipe

The replacement pipe naturally follows the line and grade of the original pipe under most conditions. However, the centerline of the replacement pipe rarely matches the centerline of the original pipe. Because the bursting head has typically a larger diameter than the replacement pipe, a cavity is created in the soil, which allows the replacement pipe to take different positions within the cavity, depending on longitudinal bending of the pipe and localized ground movements.

The position of the new pipe generally depends on the soil characteristics, site conditions and installation procedures. The effect of ground movements on the relative position of the new pipe is visible in Figure 1.11. If the soil displacements are directed primarily upwards, the new pipe has its centerline higher than the original pipe, but matches invert elevations (A, C). If the soil expansion is more uniform in all directions, the new pipe matches the centerline of the existing pipe (B). When the ground movements are directed primarily downwards, the new pipe matches the crown of the existing pipe, but has a lower invert elevation than the existing pipe (D). When the ground movements are strongly asymmetrical, the new pipe may move laterally (E).

Depending on the degree of upsize, the position of the bursting head relative to the existing pipe can interfere with the bursting operation. For example, for upsizes approaching 100%, the invert of the bursting head can tend to ride on the invert of the existing pipe. If the leading edge of the head is blunt, it tends to plow through the obvert of the existing pipe. The pulling device (rods or cable) riding against the top of the pipe prevents further upward travel. The forces required to overcome the plowing action are significantly higher than are required when the bursting head is entirely within the pipe.

The different relative pipe locations at various pipe depths may create a grade problem for pipes replaced using pipe bursting. If the existing pipe depth varies considerably along the pipe length, the replacement pipe may have different grade than the existing pipe (see Figure 1.11). Grade problems with the replacement pipe may be an issue when the pipes are laid on minimum grades and care should be taken to anticipate the ground movements and the replacement pipe position. In particular, the replacement pipe can easily deviate from the original grade near the starting or ending pit. The problem occurs when the new pipe is a stiff pipe (large diameter, thick wall), and the room in the insertion pit is too small to line it up fully with the original pipe. It also occurs when the hole in the reception pit is insufficiently large to receive the bursting head, and the replacement pipe can either push the base of the manhole downwards, or push the upper portion of the manhole upwards.

Pipe bursting may reduce sags in the existing pipe if the soil conditions around the existing pipe are uniform. However, if there is a soft zone beneath the existing pipe, the new pipe may be driven towards the soft zone and the sag deepened. Longer-than-normal bursting heads can help to maintain a straighter replacement pipe[4]. Significant sediment in the invert of the existing pipe may drive the bursting head upward relative to the existing pipe. A hard soil or rock base beneath the existing pipe may even inhibit the breakage of the underside of the pipe and cause the bursting head to break out at the top of the pipe, moving the replacement pipe substantially outside the envelope of the existing pipe. This problem has been solved in practice by redesigning the bursting head, and adapting it to promote splitting of the base of the existing pipe. Concrete encasement of the existing pipe has been shown to have a similar effect on the bursting head, if it is of non-uniform thickness. It is prudent to allow for open cut removal of concrete encased sections, when using bursting techniques.

1.5.3. Disposition of Pipe Fragments

The size and shape of the fragments of the existing pipe, and their location and orientation in the soil during and after the bursting process, are of interest with respect to the potential damage to the replacement pipe. The damage to the pipe can occur either during the bursting process, or later during soil settlement, especially if assisted by external loading.

Bursting of pipes generally creates pipe fragments of variable sizes. In a limited study of pipe fragments following busting carried out at the TTC test site, two different patterns in which the fragments settle in the soil (Atalah, 1998; Sterling, 1999) were distinguished depending on the soil type. The pipe fragments generally tend to (1) settle at the sides and bottom of the replacement pipe in sand backfill, or (2) locate all around the perimeter of the replacement pipe in silt or clay backfill. The fragments tend to locate somewhat away from the replacement pipe, with a typical separation up to 1/4 inch. This indicates a "soil flow" during the bursting process: the bursting head with its diameter larger than the replacement pipe creates the annular space, which is subsequently filled with the soil.

Orientation of pipe fragments is important when establishing the risk of new pipe perforation by the fragments (Wayman, 1995). In a study of this issue, the greatest threat to the replacement pipe was found to be the small pipe fragments with a 20-degree tip, and oriented at 90 degrees to the top of the new pipe, but the probability of actual perforation was found to be rather low (Greig, 1995).

If the replacement pipe gets only scratched in the bursting process, the problem is generally not serious for applications with no or low internal pressure, especially if the scratches are not deep. In addition, the scratching of the replacement pipe can be offset by choosing a higher than minimum pipe wall thickness (Standard Diamater Ratio - SDR). For pressure pipe applications, a sleeve pipe is typically installed during the bursting operation with the product pipe installed later within the sleeve.

1.5.4. Ground Vibrations

All pipe bursting operations create to some extent vibrations of soil particles in the ground. An extensive study of the velocity of vibrational ground movement was done by the TTC for three different pipe replacement techniques: pneumatic pipe bursting, hydraulic expansion, and static pull. The study covered a variety of job site conditions through several job sites in various regions of the U.S. and the TTC Test Site in Ruston, Louisiana. The study showed that none of the pipe bursting techniques tested is likely to damage the nearby utilities if they are at a distance of more than a few feet from the bursting head.

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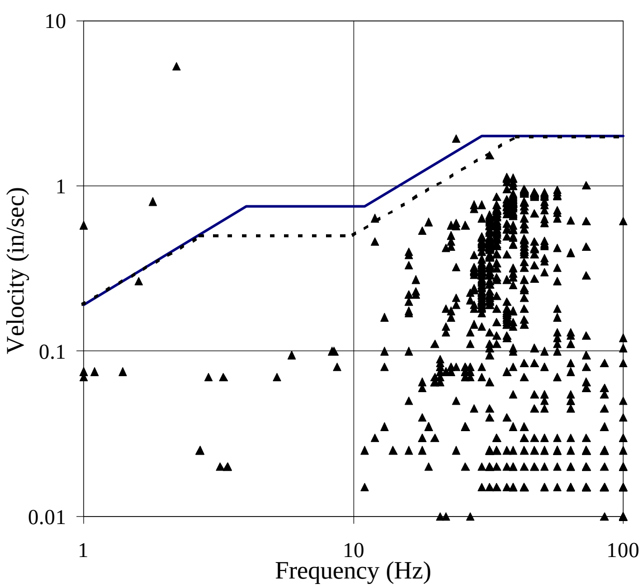
[4] If the existing pipe is clean and the bursting head properly designed, the bursting should not increase the sag, especially when static pull system is used.

The vibration levels due to bursting depend on the power (impact) applied through the bursting process, and therefore on the size and type of the existing pipe, and the degree of upsizing.

The vibrations caused by pipe bursting were also found to be unlikely to cause cracks in nearby buildings. The maximum velocity of soil particles ordinarily does not exceed the threshold criteria for cosmetic cracks in buildings, developed by the U.S. Bureau of Mines and the Office of Surface Mining, for associated frequencies of ground vibrations. The vibrations caused by pipe bursting tend to have a frequency that is well above the natural frequency of buildings. The values measured in the TTC study were in the range between 30 and 100 Hz, whereas the natural frequency of buildings is typically in a range from 5 to 11 Hz. In addition, buried pipes and structures are able to withstand much higher levels of vibration than the surface structures of similar integrity, and the vibrations are even less expected to cause distress to buried structures.



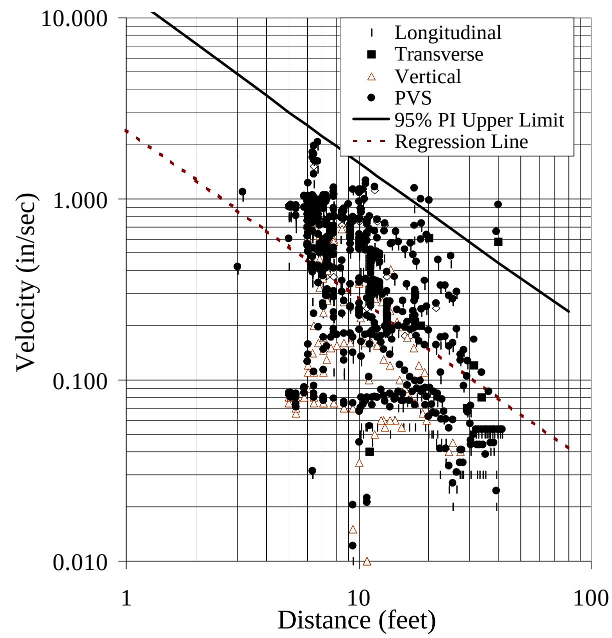


Figure 1-12: TTC study of ground vibrations. Compiled peak particle velocity vs. frequency for all test sites (left). Velocity vs. distance from the bursting head for all test sites employing pneumatic system (right). (Atalah, 1998)

Vibrations in the ground are rapidly attenuated with the distance from the source of ground vibration (Wiss, 1980; Atalah,1998). The soil particle velocities of 5 inch/second, accepted as damaging levels of ground vibration to buried structures, are unlikely to be reached at a distance greater than 2.5 feet from the bursting head. In the frequency range from 30 to 100 Hz, level of 2 inch/second (specified as the threshold for damage to sensitive surface structures) may be reached within distances of 8 feet from the bursting head. However, having sensitive buildings this close to the bursting head should be a rare occurrence when replacing pipes in a public right-of-way.

In conclusion, while ground vibrations may be quite noticeable to a person standing on the surface close to a bursting operation, the levels of vibrations recorded in the pipe bursting operations on pipes 6” to 15” in the TTC tests are very unlikely to be damaging except at very close distances to the bursting operation.

1.5.5. Effect on Nearby Utilities

Ground movements during the pipe bursting operation may damage nearby pipes or structures. Brittle pipes are the most susceptible to serious damage. Mechanical joints on pipes can easily leak, when disturbed by ground movements. The response of the adjacent pipe to the disturbance from the bursting operation depends on the position of the pipe relative to the direction of bursting (Wayman 1995). A parallel adjacent pipe is subject to transitory disturbance, as the bursting operation is progressing. If the adjacent pipe is diagonally crossing the line of bursting, it undergoes longitudinal bending as it is pushed away from the bursting line.

The severity of disturbance on the adjacent pipe depends on the type of soil. If the pipes are located in the weak soil (backfill which has not been well compacted and is still below the level of compaction of the surrounding ground), the load transfer is less significant than through a strong, incompressible soil.

The use of a sleeve in the pipe bursting intensifies the radial expansion of loading through the soil, and potentially increases risk of damage to the adjacent pipes. This is because the diameter of the bursting head relative to the existing pipe must accommodate the extra thickness of the sleeve pipe.

In order to avoid individual study in each pipe bursting project, some safety guidance has to be followed to ensure protection of pipes in a proximity of pipe bursting operation. As a general rule, both horizontal and vertical distance between the pipe to be burst and the existing adjacent pipe should be at least two diameters of the replacement pipe (Atalah, 1998). In addition, with a focus on gas and water supply systems, Transco and UK Water Industry Research Limited have issued guidelines for the protection of gray cast iron mains during pipe bursting (Leach, 1998). The guidelines identify mains at unacceptable risk of disturbance and suggest measures for their temporary protection. An acceptable proximity of adjacent pipes is determined from a series of typical proximity charts, depending on alignment of adjacent pipe relative to the pipe to be burst (parallel or crossing), type of soil (granular or cohesive), diameter of bursting head, and depth of cover over pipe to be burst. The charts are applicable for pipe sizes (both pipes to be replaced and adjacent pipes) in the size range of 3-12 inches, and at cover depths up to 6.5 ft.

The prerequisite in avoiding damage to adjacent utilities is to know their existence and location prior to the bursting. In addition to surface utility location techniques, a borehole-type logging to locate the utility lines in the zone of influence of pipe bursting from within the pipe to be burst can be used (Miller, 1998). If the utilities of concern are expected to be metal pipes, electromagnetic induction and magnetic susceptibility methods may be used from within existing pipe of non-conducting materials. These techniques locate not only the adjacent utilities, but also other obstacles like steel repair collars or steel reinforcement in the pipe to be burst that can be harmful for bursting.

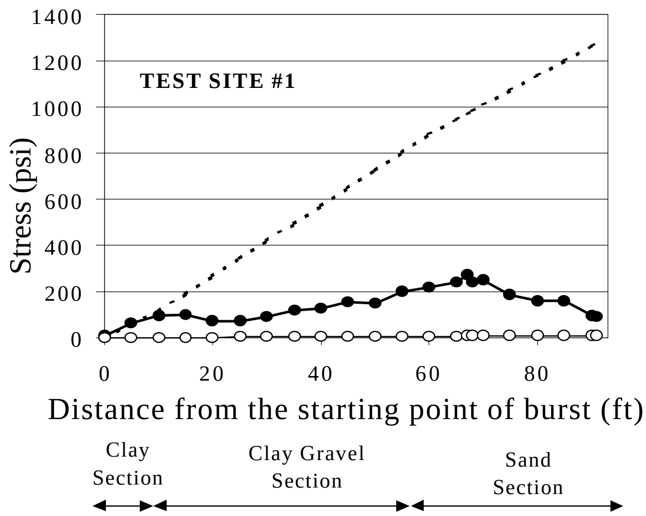
1.5.6. Stress in the Replacement Pipe

During the bursting process an axial stress appears in the replacement pipe due to the pulling force applied to the pipe behind the bursting head. The replacement pipe has to withstand this stress without failure or damage. The stress in the replacement pipe was studied during the field testing at the TTC Test Site. The testing was done for pneumatic and hydraulic bursting. It covered only a limited number of conditions, and was therefore only indicative of replacement pipe stresses.

The axial stress in the replacement pipe was calculated for two cases of soil-pipe interaction:

- If the soil does not immediately collapse around the replacement pipe, the stress in the pipe is due to the friction created by the weight of the pipe.
- If the soil collapses immediately around the pipe, the pipe friction can be calculated by methods similar to those used for estimating frictional forces in microtunneling or pipe jacking operations. The

frictional drag is a product of pipe-soil coefficient of friction, average pressure perpendicular to the pipe (which depends on soil depth and unit weight), and circumferential area of the pipe.



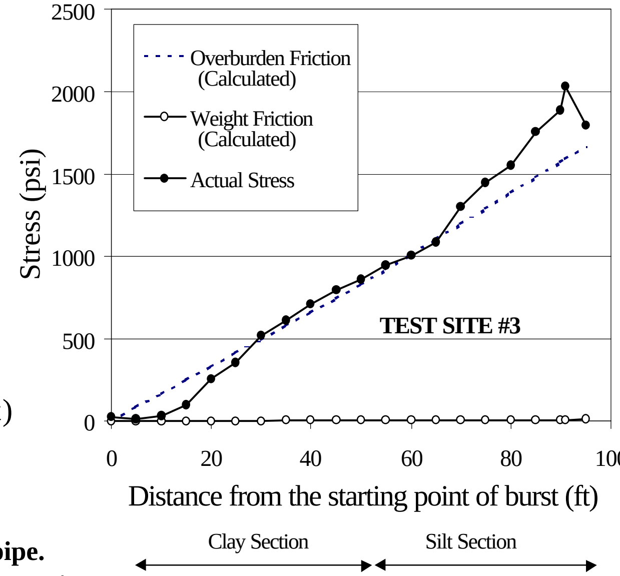


Figure 1-13: TTC study of stress in replacement pipe. Actual stress vs. calculated stress when the soil does not collapse around the pipe (left) and when it does (right). (Atalah, 1998)

The actual stress in the replacement pipe, as shown in the TTC testing, is within the range of stresses calculated for the two cases described above. Both pneumatic and hydraulic bursting create axial stress variations in the replacement pipe around the mean value (which changes with the length of bursting progression), but the magnitude of stress cycling is small compared to the mean stress level in the pipe. No direct relationship between the upsizing percentage and the stress in the replacement pipe exists because the stability of the hole created by the bursting head is the most critical parameter.

If the conditions and the length of burst are expected to induce high pipe stress and thus damage the replacement pipe, monitoring of the force applied directly to the replacement pipe is recommended. Monitoring can be undertaken using load cells or strain gauges mounted closely behind the bursting head. Measurement and recording of the pulling force is useful but does not separate the force component transferred to the pipe from the force component required to burst the old pipe and expand the cavity from the force. The stress in the replacement pipe can be lowered with the use of lubrication mud, which both delays the collapse of soil around the replacement pipe[5], and reduces the pipe-soil friction coefficient. Strain measurement undertaken on a large upsize project in Canada (Nanaimo BC) using static equipment shows that strains experienced in DR17 HDPE are well below tolerances recommended by pipe manufacturers (i.e. <5%). This is due to the fact that the majority of the total force required acts directly on the bursting head and is not transmitted to the pipe. The friction force on the replacement pipe can be as little as 10-20% of the total bursting force for the static pull method. For the pneumatic method and the hydraulic expansion method, the pulling forces are not used to directly burst the pipe and expand the cavity and hence the pulling forces are expected to be more closely related to the drag on the pipe.

[5] This is especially important for pneumatic bursting in non cohesive soils where, without lubrication, the vibrations would cause the soil to collapse around the replacement pipe in a very short time, grabbing the pipe. If the replacement pipe is a polyethylene pipe, it can stretch the like a rubber band.

1.6. Feasibility of Pipe Bursting

1.6.1. Cost of Pipe Replacement

The cost of pipe replacement depends on various factors (type and size of the host pipe, upsizing requirements, depth, ground conditions) and is generally determined on a case-by-case basis. In 1999 the TTC sent out a cost-related questionnaire to contractors and municipal agencies in the USA and established a rough price range for actual bids on pipe bursting projects. The following two graphs show the result of this survey for (1) size-for-size pipe replacement and (2) pipe replacement with upsizing.

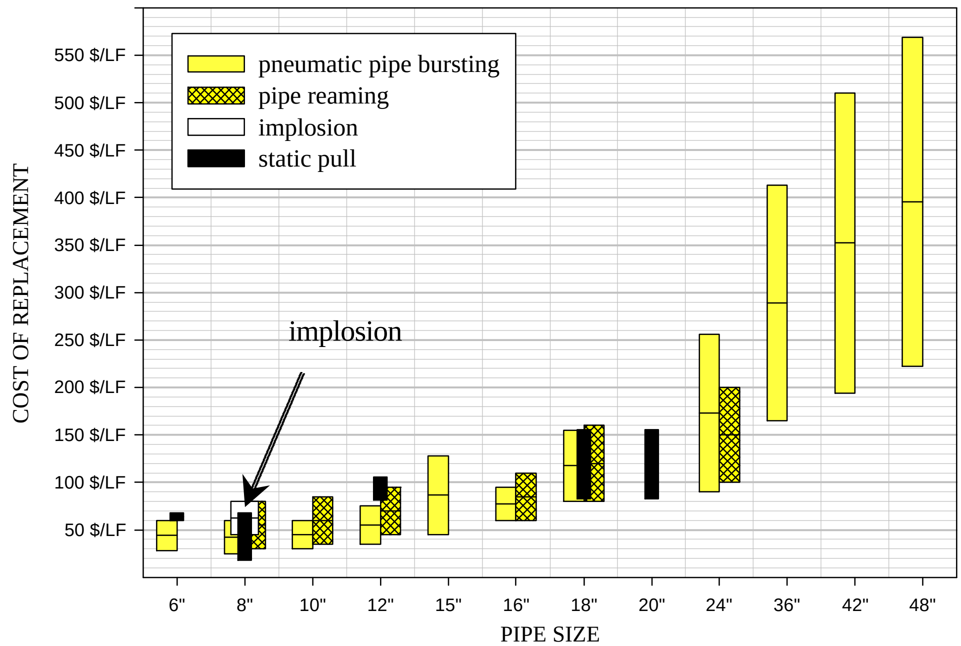


Figure 1-14: Bid cost of size-for-size pipeline replacement (1999)

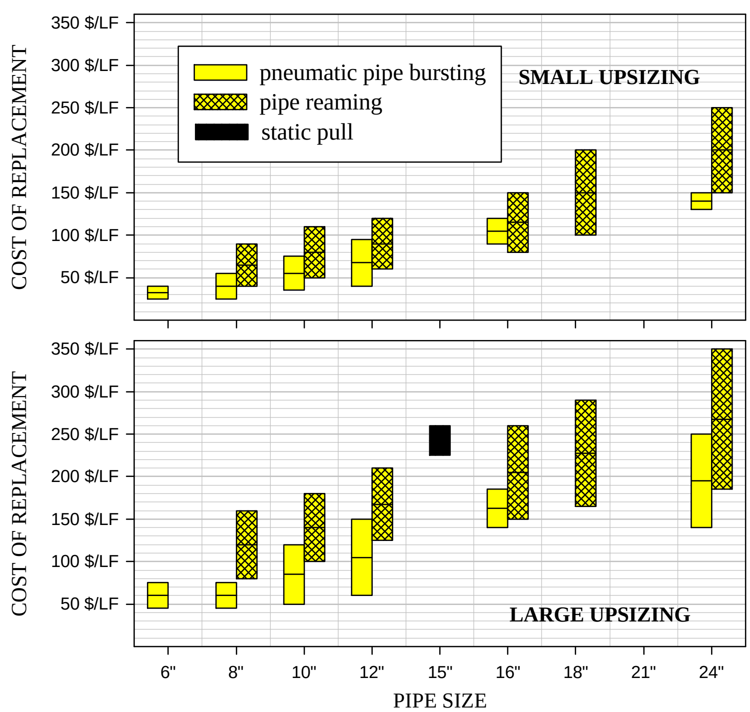


Figure 1-15: Bid cost of pipe replacement with upsizing (1999).

In the graph, small upsizing refers to increase in pipe diameter up to 20%.

Note: Pipe bursting is a patented process and is all inclusive of all methods used to burst the pipe. Advatica Technologies, Inc., formerly British Gas Technology, Inc. owns the patent and royalty payments must be paid if the process is used.

1.6.2. Comparison with the Open Cut Replacement

Open cut replacement may be a preferred option of pipe renewal when the pipeline is shallow and the trenching does not create inconvenience. However, under many conditions, pipe bursting has substantial advantages over the open cut replacements. It is (1) much faster, (2) more efficient, (3) often cheaper, (4) more environmentally friendly, and (5) less disruptive to surface features than open cut.

The cost advantage is especially notable in sewer line replacement, where an enhanced depth of lines increases the cost of open cut replacement through extra excavation, shoring, dewatering, etc., while has minimal effect on the cost of pipe bursting. One example of cost comparison of pipe renewal with open cut vs. pipe bursting is shown in Figure 1.14 (Poole et al 1985). Additional advantages of pipe bursting over the open cut replacement are indirect cost savings, due to (1) less traffic disturbance, (2) shorter time for replacement, (3) less business interruption, (4) less environmental disturbance, etc.

Pipe bursting usually produces less ground disturbance than open replacement. In open cuts, there is stress relief in the ground as the trench is dug, and the unconfined ground moves inward and downward. Also, service lines parallel to the trench displace laterally and downward, while service lines crossing the trench sag. Shoring can reduce these movements, but usually does not prevent them.

Open cut replacement that involves cutting through a road pavement structure can reduce the life of the pavement structure through backfill settlement in addition to the adjacent ground movements (Rogers 1995). Social costs such as traffic and business disruption, length of time and mess for open cut, reduced pavement life, environmental mitigation and others all can increase the total <u>effective</u> cost of open cut construction. Even when bursting costs the same or slightly more than open cut, the decrease in effective costs makes bursting very attractive.

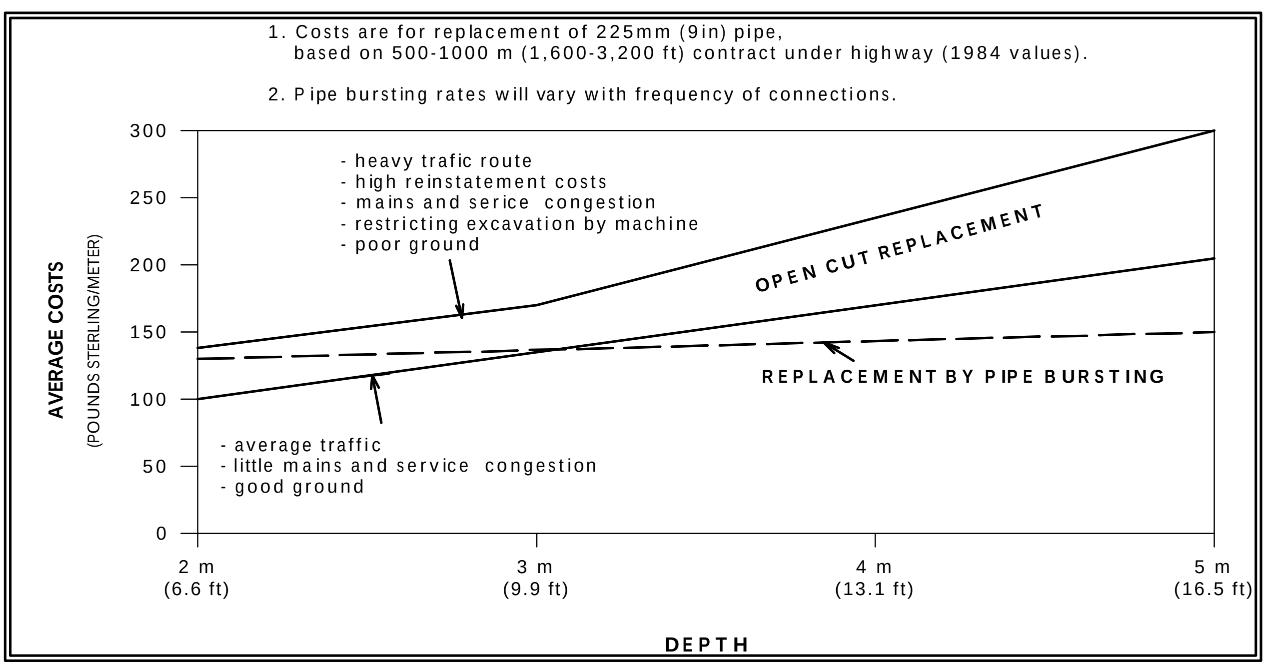


Figure 1-16: Cost comparison between pipe bursting and open cut pipe replacement, a case study from U.K. (Poole et al 1985).

1.6.3. Comparison with Other Rehabilitation Methods

The main advantage of pipe bursting over other trenchless rehabilitation methods, such as cured-in-place (CIP) pipe, fold-and-form (FF) pipe, sliplining, etc., is the ability to upsize service lines.

Significant increases in pipe diameter can be achieved, however each increase is associated with increased levels of ground displacement, and can be damaging to nearby structures if they are close to the existing pipe or if they are not relieved by local excavation. The limitation in upsizing capability is related to many factors, such as ground conditions, pipe depth, ground water conditions, local excavation history, and proximity of other utility and pipelines.

While relining methods of rehabilitation follow the grade of the existing pipe, pipe bursting can modify it under particular circumstances. This ability can be advantageous, if used to correct unwanted sags in the existing pipe, but can also be unfavorable, if the existing grade should not change. There are methods to prevent unwanted grade alteration during pipe bursting, as was mentioned earlier in the section on positioning of the replacement pipe. These are generally slightly more expensive than conventional bursting, but can be considered if grade is critical.

Pipe bursting may be the only choice for trenchless improvement of an existing pipe in very bad shape if other rehabilitation methods are rejected as unsuitable. However, partially collapsed pipes usually are not suitable even for pipe bursting. One study, which was carried out to establish the feasibility and cost effectiveness of pipe bursting for renewal of corroded cast iron mains, showed that pipe bursting is generally the preferred option for corroded pipes with more than 80% internal and 60% external wall thickness loss (Asquith 1989).

1.7. Market for Pipe Bursting

Pipe bursting is extensively used to renew aged pipelines in the USA and worldwide, and the use of this method is increasing. A total footage of pipe replacement per year was, in the USA, approximately 16,000 ft or less in 1994, and about 500,000-ft in 1997. The market is favorable, and the total footage is growing at approximately 20% per year (Hopwood, 1998).

Pipe bursting is currently more popular in the sanitary sewer market in the USA, than in the potable water market where it is expected to eventually become more common as well. Its application in the water market was enhanced by the approval of HDPE for potable water by AWWA in early 1990s, but its use for water pipe replacement has still been slow. This is thought to be due to owners and engineers' reluctance in allowing HDPE as an approved watermain material selection.

2. Applicable References

2.1. Standards

2.1.1. American Society for Testing and Materials (ASTM) Standards

The process of pipe bursting is currently not covered by ASTM Standards. Only the plastic pipes, which are used as replacement pipes, are covered.

(Unless otherwise noted, all ASTM Standards should be for the latest year of publication.)

ASTM C1208/ C1208M-99a	Standard Specification for Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting, and Tunnels
ASTM D 638	Test Method for Tensile Properties of Plastics
ASTM D 1248	Specification for Polyethylene Plastics Molding and Extrusion Materials
ASTM D 1599	Test Method for Short Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings
ASTM D 3034	Type PSM Poly Vinyl Chloride (PVC) Sewer Pipe and Fittings
ASTM D 3212	Specification for Joints for Drains and Fuel Plastic Pipes Using Flexible Elatomeric Seals
ASTM D 3350	Specification for Polyethylene Plastic Pipe and Fitting Materials
ASTM F 477	Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
ASTM F 714	Standard Specification for Polyethylene Plastic Pipe Based on Outside Diameter

2.1.2. Plastics Pipe Institute

Standards for Plastic Piping, September, 1990.

2.1.3. National Sanitation Foundation (NSF)

Standard No. 14 - Plastics Piping System Components and Related Materials, 1988.

2.2. Reports

2.2.1. Trenchless Technology Center (TTC)

Atalah, A. (1998). *The Effect of Pipe Bursting on Nearby Utilities, Pavement and Structures*, Technical Report No. TTC-98-01, Trenchless Technology Center, Louisiana Tech University, Ruston, LA.

2.2.2. Other

Many other reports and technical papers are available that describe the various pipe bursting techniques, report case histories and describe field and laboratory experimentation on the effects of pipe bursting. These papers are listed in the bibliography at the end of these guidelines. Only specific references are listed below.

Fraser, R., N. Howell and R. Torielli, 1992. "Pipe Bursting: The Pipeline Insertion Method, *Proceedings of No-Dig International '92,* Washington DC, ISTT, UK.

Howell, N., 1995. "The Polyethylene Pipe Philosophy for Pipeline Renovation," *Proceedings of No-Dig International'95,* Dresden, Germany, ISTT, UK.

Leach, G., and P.C.F. Ng, 1998. "Damage Control Procedure for Pipe Splitting," *Trenchless Technology Research*, a supplement to Tunnelling and Underground Space Technology, Vol.13, Suppl. 1-2, 1998, ISTT, United Kingdom, Pergamon, pp.41-46

Leach, G. and K. Reed, 1989. "Observation and Assessment of the Disturbance Caused by Displacement Methods of Trenchless Construction," *Proceedings of No-Dig International '89,* London, UK, pp. S2.4.1-2.4.12.

Miller, R.J., and M.J. Culig, 1998. "Borehole Geophysics Clears Way for Pipe Bursting," Trenchless Technology, Vol.7, No.7, July 1998, Peninsula, OH, pp.34-35

Poole A., R. Rosbrook, and J. Reynolds, 1985. "Replacement of Small-Diameter Pipes by Pipe Bursting," *Proc. of 1st Intl. Conf. on Trenchless Construction for Utilities: No-Dig '85*, April 16-18, London, UK.

Rogers, C., 1995. *Ground Displacements Caused by Trenching and Pipe Bursting*, Loughborough University of Technology, UK.

Rogers, C.D.F., 1996. "Ground Displacements Caused by Trenching and Pipe Bursting," *No-Dig International*, Feb. 1996, ISTT, London, UK.

Topf, H., 1991. "XPANDIT Trenchless Pipe Replacement," *Proceedings of North American No-Dig'91*, Kansas City, MO, NASTT, Arlington, VA

Topf, H., 1992. "XPANDIT Trenchless Pipe Replacement," *Proceedings of No-Dig International '92*, Washington DC, April 5-8, 1992, NASTT, Arlington, VA

Tucker R., I. Yarnell, R. Bowyer, and D. Rus, 1987. "Hydraulic Pipe Bursting Offers a New Dimension," *Proceedings of No-Dig International '87,* April 14-16, ISTT, London, UK

3. Design Considerations

Design considerations evolve from ground conditions, groundwater conditions, degree of upsizing required, construction and depth of the existing pipeline, etc. This chapter discusses these issues and their relevance, and gives some general guidance about the selection of replacement pipe, bursting length, necessity for the use of a sleeve pipe, etc.

3.1. Ground Conditions

The most favorable ground conditions for pipe bursting projects are where the ground surrounding the pipe can be compacted readily by the bursting operation as it is displaced. This will limit the outward ground displacements to a zone close to the pipe alignment. It is also favorable if the soil surrounding the pipe will allow the expanded hole to remain open while the replacement pipe is being installed. This will lower the drag on the replacement pipe and thus lower the tensile stresses to which the pipe is exposed during installation.

Somewhat less favorable ground conditions for pipe bursting involve densely compacted soils and backfills, soils below the water table and dilatant soils (soils that expand in volume as they are sheared, e.g. angular sands)[6]. Each of these soil conditions tends to increase the force required for the bursting operation and to increase the zone of influence of the ground movements. Special soils such as highly expansive soils or collapsible soils will also cause problems. For most soil conditions, it is simply necessary to provide the required power to effect the burst, displace the soil and pull the replacement pipe in over the length of the burst and to consider the potential effect of the ground displacements and vibrations on adjacent utilities and structures. Longer bursts can be accomplished more easily in favorable ground conditions.

In some ground conditions, problems can be caused by the wrong selection of the pipe bursting system. For example, sands and crawfish type soils below groundwater table can cause a problem for pneumatic pipe bursting because, due to the vibrations, the ground movements seem to steer away the soil and the pieces of broken pipe above the pipe, thus reducing the weight on the top of the new pipe. If the replacement pipe is a light-weighted polyethylene pipe, it will tend to rise upward, sometimes as much as two feet above the original invert. Static pipe bursting eliminates this problem and seems to be a better alternative in such ground conditions.

When the soil provides a high friction drag on the pipe and the length of run is long enough to generate high tensile forces on the replacement pipe, bentonite or polymer lubrication muds may be injected into the annular space behind the bursting head to help keep the hole open and to reduce the frictional drag on the replacement pipe.

The base soil should be able to support the weight of the pipe bursting unit and product pipe and the ground conditions should be fairly uniform around the pipe and consistent along the length of the pipe. If

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[6] Not all pipe replacement methods are equally affected by ground conditions. For example, pipe reaming process is rarely disturbed by the water table and soil types in themselves, except in clays which can sometimes limit the degree of upsizing.

there has been erosion of the soil around the pipe, the bursting head and the following pipe will tend to displace 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 ground will displace mostly upwards towards the ground surface and the new pipe will tend to match invert with the old pipe. If the pipe is deep relative to its diameter, the ground will tend to displace more radially around the old pipe and the new pipe will tend to be concentric with the old pipe. 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.

3.2. Groundwater Conditions

Pipe bursting below the groundwater table increases the difficulty of bursting operations. Bursting in saturated soil can cause the water pressure to rise around the bursting head, unless the soil has a high enough permeability to allow the water pressure to dissipate quickly. The rise in water pressure causes the effective stress in the soil to drop and may cause the soil to behave more like a viscous fluid. When the fluidized soil displaces the surrounding soil, the ground movements tend to be more extensive and nearby services may displace more easily. In certain soil conditions, groundwater can have a buoyant and lubricative effect on the bursting operation, with groundwater flowing towards open insertion pit and reception pit along the existing trenchline. During pipe bursting, insertion and receiving pits are preferably kept dry. If the groundwater is removed to a large degree (e.g. by well pointing), consolidation/densification of the soil surrounding the existing pipe can result, significantly increasing bursting forces.

3.3. Host Pipe

3.3.1. Material

Most brittle pipe materials make good candidates for pipe bursting. Ductile pipes may be scored and then slit as in the pipe splitting operations described above. Pipes made of non-ductile abrasive material but with ductile reinforcing are the most difficult to replace using most pipe replacement techniques.

Common types of pipe and their bursting characteristics are indicated below:

- Clay pipes are good candidates for bursting. They are brittle and fracture easily. Newer clay pipes may have PVC joints. Such plastic fittings may hinder the bursting operation slightly and may need special application tools but do not represent a real concern. The fragments of clay pipe may be sharp and there is some level of concern about the gouging or scoring of the replacement pipe and eventual point loading on the replacement pipe. Sacrificial external sleeve pipes are often used to ensure protection for plastic replacement pipes for high pressure pipe applications. There is much less concern for gravity sewer pipe applications.
- Plain concrete pipes are good candidates for bursting. They are relatively brittle and tend to fracture easily in tension especially when in a deteriorated condition. Thick plain concrete or reinforced encasements or repairs to the pipe may cause difficulty in bursting.
- Reinforced concrete pipes present difficulty unless the concrete and reinforcing steel is deteriorated. They may be burst with powerful enough equipment but careful evaluation may be needed if the pipes are more than lightly reinforced and are not significantly deteriorated.
- Cast iron pipes are good candidates for bursting. The pipes are relatively brittle even when in good condition. The fragments of cast iron pipe may be sharp and there is concern about the gouging or

scoring of the replacement pipe and eventual point loading on the replacement pipe. Sacrificial sleeve pipes are often used to ensure protection for plastic replacement pipes for high-pressure pipe applications. Special application tools and protection of the winch cable, when used, may need to be considered. Ductile repair clamps, service saddles and fittings can cause problems for the bursting operation and hardened cutter blades may be incorporated to cut through such clamps.

- Steel and ductile iron pipes are not good candidates for pipe bursting. They are strong and ductile. In smaller diameters, they may be replaced using pipe splitting techniques.
- PVC and other plastic pipes may be replaced using an appropriate combination of bursting and splitting techniques according to the strength and ductility of the pipe.
- Asbestos cement pipes are generally good candidates for bursting. Care should be taken to determine the class of the existing pipe. Thicker, higher tensile strength pipes (such as AC watermain) tend to "ball up," increasing required bursting forces. Modifications to standard bursting heads should include cutter blades to split the pipe.

3.3.2. Size and Upsizing Requirements

In the smaller size ranges, a small diameter pipe may be harder to burst than a larger size pipe, because the walls are thicker in relation to the size of tool. It is considered that an 8-inch pipe is easier to burst than a 4-inch pipe.

The host pipe diameter and the required upsize of the new pipe determine machine selection. To date, upsizing by up to 30% of the original pipe diameter is common, and greater upsizing has been successfully completed in many projects. With larger diameter pipes (more than 18 inches in diameter), projects with a high upsizing percentage must be carefully examined in terms of required forces and ground displacements.

3.3.3. Depth and Profile

The depth of the host pipe affects the expansion of surrounding soil. Also, water table considerations vary with depth. Insertion and reception pits grow larger and more complex as the depth increases.

The existing profile of the bursting run can also affect the planning and execution of the pipe bursting operation, especially changes in grade or bends. If pre-installation video inspection reveals a sag in the existing sewer line larger than acceptable (one-half the diameter of the existing pipe, for example), the sag needs to be eliminated in order to install the replacement pipe with an acceptable grade and without the sag. The sag can be eliminated by local excavation and bringing the bottom of the pipe trench to a uniform grade in line with the existing pipe invert. Some reduction of sag may be expected from the bursting operation but the extent to which the problem is corrected will depend on the relative stiffness of the ground surrounding the sag section (especially beneath). The presence of rock under the existing pipe may create a 'bump' in the replacement pipe. This is generally considered unacceptable, but in actual fact is quite rare.

3.4. Surrounding Utilities

Surrounding utilities can affect the location of insertion and reception pits. Utilities that interfere with or may be damaged by the burst should be located and exposed prior to the burst. For typical pipe bursting operations, underground utilities in moderate condition are unlikely to be damaged by vibrations at distances of greater than 2.5 feet from the bursting head (Atalah 1998) and ground displacements are unlikely to cause problems at distances greater than 2-3 diameters from the pipe alignment. (Rogers 1995).

3.5. Other Factors

While not common in all jurisdictions, occasionally pipe bursting takes place through horizontal or vertical curves. Although many long bursts through relatively short radius curves have been successful using both static (rod) and pneumatic systems, careful consideration of methodology is required. It is prudent to plan for the space and excavation requirements of a pit at the midpoint of a run, such as at the apex of a curve.

The repair history of the line(s) to be burst should be noted carefully from utility records or video inspection. Repairs may involve heavy repair clamps that can halt a bursting operation. Sometimes, repair clamps can be successfully burst using a cutting blade in combination with the bursting head unless the cutting blade happens to line up with the bolts of the repair clamps.

Thick root masses are also considered obstacles because roots wrapped tightly around the old pipe can absorb a lot of shock without breaking and hence make the pipe harder to break. Obstructions in the pipe such as a heavy solids build up, dropped joint, protruding service tap or collapsed pipe, may prevent the pipe bursting operation completely. If the obstruction cannot be removed from the pipeline by conventional cleaning equipment, it may be necessary to excavate and carry out point repairs prior to bursting. Otherwise, the bursting process may slow or stop. The risk and potential consequences should be considered before starting the job to determine whether to deal with the problem if it should arise or whether to take preventative action. Generally, provisional items in the contract for all potential eventualities will help confirm the final costs.

3.6. Replacement Pipe

HDPE and MDPE are the most common new pipe materials. The main advantages of PE pipe are its continuity, flexibility, and versatility. The continuity is obtained by hot fusing long segments together in the field prior to insertion. The continuity during the installation reduces the likelihood of needing to interrupt the bursting process. The flexibility allows bending of the pipe for angled insertion in the field. In addition, PE is a versatile material that meets all the other requirements for gas, water, and wastewater lines. The relatively high thermal expansion coefficient is a disadvantage of PE pipes, although this is not generally a concern once the pipe has stabilized (cooled) in situ. Thrust restraint devices such as flanges poured into manhole walls can counteract long-term creep or temperature changes, if wide variations in temperature are anticipated.

Experience appears to show that it is generally the long-term loading requirements that govern selection of pipe wall thickness for non-pressure (e.g. sewer) pipe, rather than pull (tensile) strength. An additional 10% of the long-term thickness requirement can be allowed for sacrificial scarring. Further in-depth studies will be required to compile enough data to verify wall thickness design, especially for pressure pipe applications.

If there is insufficient space to fuse and string the PE pipe, PVC pipe with mechanical, spline-locking design joint (CertaLok and Aquamine Restraint Joint) is a possible substitute.

Another recently developed material for the replacement pipe is a special flush-joint ductile iron pipe suitable for pipe jacking or pipe bursting applications. Many water utilities are familiar and comfortable with ductile iron pipe. Development of this form of ductile iron pipe in the early nineties has allowed ductile iron pipe to be used for direct jacking operations as a carrier pipe, for either sewer or potable water applications.

Other types of replacement pipe used in pipe bursting include cast iron pipe, vitrified clay pipe, and reinforced concrete pipe. If the type of pipe requires installation in segments rather than a continuous length and if, as is normally the case, the pipe joint will not withstand significant tensile force, the bursting head and pipe installation technique needs to be modified. Typically, sectional rods are passed from the bursting head through the replacement pipe and these rods are used to clamp the replacement pipe in compression and to allow the replacement pipe string to be pulled from the rear of the pipe string rather than from the front. The installation is slowed because the pipe sections must be added during the bursting operation and the pulling arrangement reconnected. It is preferable that all pipe joints are designed for trenchless installations, i.e. to have a nominally flush exterior profile.

When selecting the replacement pipe it is common to request a light-colored pipe to facilitate CCTV inspection after the installation (see section 4.8 - Testing of the Replacement Pipe)

3.7. Number of Pits and Length of Bursting

The location of insertion and access pits should be such that their number is minimized and the length of bursting maximized consistent with the equipment available for the burst and the expected stress on the replacement pipe.

In sewer replacement jobs, the burst length is usually from manhole to manhole. An intermediate manhole can be passed through with proper preparation. Longer than normal bursts may need larger tools and lubrication mud to reduce friction. Also, the size of the existing pipe and the upsizing percentage have an effect on the safe length of bursting.

For relatively large upsizes (greater than 2-3 sizes), reuse and rehabilitation of the existing manhole may prove to be prohibitive cost and production-wise. In these cases, it will be more cost-effective to replace each manhole.

It is recommended that clauses in contracts should clearly define a pit as “all excavation required per manhole location.” A contractor may be required to excavate in two directions in the case of an insertion pit, and thus expect to be paid for two pits at one manhole location.

3.8. Protective Sleeves

In water main replacement, an internal protective sleeve may be used to protect the interior of the water main from contamination from dirt, oil, exhaust gas, etc. caused by equipment and hoses that must be installed in the replacement pipe for the bursting operation to function. The static pull method does not require hoses or equipment in the replacement pipe if a continuous replacement pipe is used and hence, for this condition, does not require an internal protective sleeve or pipe for potable water applications. The exception to this condition is when a lubrication hose needs to be threaded through the continuous pipe.

In pressure pipe applications using plastic pipe, an external protective sleeve pipe may be used to prevent damaging stress concentrations and lowered failure pressures from occurring due to potential gouges caused by the pipe fragments in the ground. In this case, the external sleeve pipe is installed during the bursting operation and the product pipe can be installed later in a separate operation. When an external protective sleeve pipe is used, the size of the bursting head must be increased to accommodate the carrier pipe thickness and the annular space required for the product pipe to be inserted. This increased diameter increases power requirements for the bursting and also increased the extent of ground movements surrounding the bursting head.

Alternately, the replacement pipe can be designed with sacrificial thickness to allow for the possibility of scoring. Allowable maximum scoring (10% for example) can be set out in the contract or performance specifications. One or two DR decreases (increase in thickness) could be enough to allow for sacrificial scarring. This option deserves consideration in the context of the cost of protective sleeves.

3.9. Effect of Pipe Bursting on Nearby Structures

The effect of pipe bursting on nearby structures and adjacent pipes needs to be carefully analyzed. The design of a pipe bursting job has to assure admissible soil displacements and, if necessary, to include damage prevention measures (local excavations made to relieve induced stresses). Laboratory studies, field studies, analytical and simulation techniques have been used to predict the soil displacements along the pipe adjacent to the pipe being burst (Atalah 1998, Leach and Reed 1989, Rogers 1995/96). When the ground displacements have been estimated, the effect on an adjacent pipe can be analyzed using a separate analysis (e.g. beam-on-an-elastic foundation analysis) or by engineering judgement involving the condition and stiffness of the pipe.

4. Construction Considerations

Pipe bursting is typically performed in the following steps:

- pre-construction survey
- cleaning/pigging of line, if needed
- CCTV inspection, if needed
- excavations at services for temporary bypass
- setting up temporary bypass/connections to customers
- excavation of entrance and reception pits
- connecting the replacement pipe segments into a continuous pipe, if applicable
- set up of:
- winch and insertion of pulling cable, or
- hydraulic pulling unit and insertion of pulling cable, or
- rigid pulling rods
- installation of hoses through the replacement pipe and attachment of those to the bursting head:
- air supply hoses for pneumatic system, or
- hydraulic hoses for hydraulic expansion
- lubrication hoses if applicable
- attachment of either pulling cable or pulling rods to the bursting head
- pipe bursting and simultaneous replacement with:
- external sleeve pipe, or
- product pipe
- removal of bursting head
- installation of product pipe, if not already installed
- removal of hoses
- reconnection to manholes or existing pipe, as applicable
- replacement pipe testing
- reconnection of services
- additional quality control testing
- site restoration

This chapter describes some of these steps which are distinctive for pipe bursting.

4.1. Service Excavations

Service connections (sewer, gas and water) to the pipeline being burst can create problems during bursting regardless of whether they are excavated prior to bursting or not. The services are usually excavated prior to bursting to provide temporary bypass service and to protect the services during the bursting operation. If the connections are not excavated prior to bursting, they can easily be damaged and the damage to the service lateral may happen at some distance from the connection – in a location where the damage would not be seen during the connection process. However, if the connections are excavated prior to bursting, a hump in the profile of the replacement pipe at this location is often created. This due to the reduced resistance to upward movement of the replacement pipe at this point. This problem could be reduced by excavating beneath the pipe, as well as above the pipe, at the connection. For the reaming or pipe eating process that have less impact on the service lines, a wye with a riser to the surface can be installed on the service line about 2-3 feet from the main, and a plug between the main and the wye inserted prior to bursting. During the bursting the riser can be monitored and after bursting the connection to the main can be excavated and reconnected.

4.2. Insertion and Reception Pits

For sewer applications insertion and reception pits are usually excavated in front of manholes, or manholes are removed and replaced. For replacement of gas and water lines, service pits can be expanded and used for the insertion and reception pit. All pits should be prepared and shored in an approved manner. For all static rod and cable pull machines, the machine should be properly braced to resist the horizontal force necessary for the bursting operation. This may require the pit or manhole wall to have a thrust block with proper structural capabilities. Inadequate structural capacity of the pit wall or thrust block to resist the pull/push forces can cause wall deformation or failure and surface heave near the wall. Sudden movements of jacking rigs and cable pull systems can raise safety concerns for the contractor and bystanders.

Different pipe bursting systems have different requirements in terms of the space required in the reception pit. Some systems may be able to operate within existing manholes and others may need to excavate a pit for the pulling frame.

The insertion pit must be large enough to allow the pipe to be inserted. For continuous HDPE pipes, this means that the pipe must be able to be fed from the surface into the existing pipe alignment without overstressing the pipe in bending. Manufacturers' guidelines on minimum bending radius need to be closely adhered to. Instead of creating a long insertion pit, it is sometimes possible to create a pipe entry path using an impact mole or similar device. This is then expanded using the pipe bursting expansion head and the pipe is fed through this new hole to the level of the pipe being replaced.

4.3. Replacement Pipe Preparation

When a replacement pipe is of polyethylene, it is delivered onto the site in segments and butt-fused into a continuous pipe on site. The maximum length to be installed is limited by the space available for the pipe to be assembled prior to bursting and by the maximum tension expected in the pipe during the pull in operation. Fusion is carried out prior to the bursting operation, so that all fused joints can be checked and there is no delay due to fusing during the bursting operation itself. Pipe fusing is to be performed by personnel trained in the use of butt-fusion equipment and following the recommended methods for the new pipe connections. Data loggers can be used to record length of heating, fusing and cooling time, as well as temperature and pressure of each joint to ensure and record quality control.

The replacement pipe should not be dragged over the ground surface (unless such damage is allowed for by sacrificial pipe thickness). Instead, the pipe should be moved over rollers or slings for insertion and transportation. The pipe ends should also be capped to prevent any ingress of foreign matters for water or gas piping.

4.4. Equipment Installation

When the winch and pulling cables are used to pull the bursting tool through the pipe, the winch is placed into an reception pit, and the cable pulled through the pipe and attached to the front of the bursting unit in an insertion pit. The winch helps to ensure the directional stability in keeping the unit on the line of the existing pipe. The winch must supply sufficient cable in one continuous length so that the pull may be continuous between winching points. The winch, cable and cable drum must be provided with safety cage and supports so that it may be operated safely without injury to persons or property.

When rigid pulling rods are used instead, they are threaded from the reception pit through the existing pipe until the pipe insertion pit is reached. The rods are then attached to the bursting head.

4.5. Bursting Operation

The bursting of the old pipe can be performed as a continuous action if the replacement pipe is continuous and the winch with continuous cable is used.

When rigid rods are used as a pulling unit the bursting operation temporarily halts, for each rod sections to be unthreaded and removed from the reception pit. In addition, when the pipe is installed in segments, the preparation of each successive pipe segment also interrupts the operation, as it includes the following steps:

- Changing the machine from pull to push
- Removing the pulling plate from the previous joint installed
- Setting the new pipe section and mating it to the previous pipe section:
    - Lubricating the coupling with approved materials if required
    - Setting the o-rings or gaskets
    - Pushing the two pipes together
- Pushing rods back through the new section of the pipe
- Setting the pulling plate to attach the rods to apply the pulling force
- Changing the machine back to pull mode

The process continues until the bursting head is pulled completely back into the reception pit, ending the replacement.

4.6. Reconnection of Services and Annular Space Sealing

The installed pipe is left for the manufacturer's recommended time, but normally not less than four hours, prior to any reconnection of service lines, sealing of the annular space in the manhole wall or backfilling of the insertion pit. This period allows for pipe shrinkage due to cooling and pipe relaxation due to the tensile stresses induced in the pipe during installation.

Following the relaxation period, the annular space in the manhole wall may be sealed. Sealing is extended a minimum of 8 inches into a manhole wall in such a manner as to form a smooth, watertight joint. Ensuring a proper bond between the PVC or PE replacement pipe and the poured manhole wall joint is critical.

Service connections can be reconnected to the new pipe with specially designed fittings by various methods. The saddles, made of a material compatible with that of the pipe, are connected to the pipe to create a leak-free joint. Different types of fused saddles (electrofusion saddles, conventional fusion saddles) are installed in accordance with manufacturer's recommended procedures. Connection of new service laterals to the pipe also can be accomplished by compression-fit service connections. Installation procedures and equipment are to follow manufacturer's installation instructions. After testing and inspection to ensure that the service meets all the required specifications of the service line, the pipeline returns to service. In case of groundwater, the replacement pipe may float at the point of excavation and require careful regrading prior to service reconnection.

4.7. Manhole Preparation

All confined space safety procedures apply as appropriate. Entry and exit holes from manholes must be enlarged to accept the new pipe as required. The sewer manhole invert may need modification to allow tool passage. In cases of large upsize or when dealing with large diameter pipe, and where surface conditions allow, complete replacement of manholes may be the simplest and least expensive option. This also can be beneficial in that a complete new system results.

4.8. Testing of the Replacement Pipe

A few tests of the replacement pipe are normally performed in a pipe bursting job. The first test is before the pipe has been sealed in place at the manholes, and before any service reconnections have been made performed (low-pressure air test). The purpose of this test is to check the integrity of joints that have been made, and to verify that the replacement pipe has not been damaged during installation.

The second test is the service lateral connections test, performed after all service laterals have been completed for a particular section (smoke test). This test is to verify the integrity of reconnections at points where they join the replacement pipe and existing service lines.

Additional acceptance testing following the applicable test procedures is performed if required. A television inspection videotape record is a common request.

4.9. Troubleshooting in Pipe Bursting Jobs

Pipe bursting of existing lines is not always successful. This is usually because the bursting head gets stuck at an unexpected obstruction in or around the pipe. Typical examples are:

- Steel repair clamps on water pipes
- Concrete encasement of pipes
- Root balls of trees that encircle pipes

It is possible to use more powerful equipment and specially designed bursting heads to offset these difficulties but, if the difficulties are not anticipated ahead of time, then an unscheduled dig may be needed to retrieve the bursting head. Also, obstructions and unusual conditions surrounding the pipe may increase ground vibrations and accentuate ground movements in particular directions.

5. Bid Documents

5.1. General

The bid documents are prepared by the owner/engineer, and should provide the contractor information needed to prepare competitive bids for construction. Typical bid documents should include the following: Invitation for Bids, Scope of Work, Plans, Specifications, Site Investigation Report, Procedures for Protecting Existing Structures and Site Features, Inspection Procedures, Minimum Performance Requirements, and Performance Period.

Satisfactory evidence may be requested that the contractor has regularly engaged in furnishing products and performing construction work as proposed, and has the capital, labor, equipment, and material to execute the work required by contract documents.

Since pipe bursting is a specialized installation technique, some of the bid documents will have unique requirements. These special requirements are detailed in the following section.

5.2. Minimum Performance Requirements

Minimum performance requirements are established in the contract documents to ensure that the pipeline, as installed, will perform as designed. The criteria typically established for gauging performance include hydraulic characteristics, grade tolerances, water infiltration, internal pressure tests, and protection of adjacent structures. Causes for rejection of a pipe replacement job include physical defects of the pipe, such as concentrated ridges, discoloration, excessive spot roughness, pitting, visible cracks, foreign inclusions, and varying wall thickness.

Other criteria may include allowable ground displacement, allowable work hours, and safety requirements.

5.3. List of Applicable References and Standards

A list of references and standards for equipment, materials, safety, etc., should be provided to the contractor for use in planning and bid presentation.

5.4. Site Investigation Report

Site investigation information, including existing utility network investigation, surface investigation and sub-surface investigation, allows the contractor to prepare a bid that is consistent with the probable soil conditions.

This information should be presented to the contractor prior to the bid, and the contractor should examine the project site on his own. Clauses transferring all responsibility for ground conditions to the contractor are not always accepted by the courts and, in addition, they also typically cause contractors to increase their bid price to cover the additional risk of unexpected ground conditions. On the other hand, failure to collect appropriate and reasonably available site information during the bid period may not relieve the contractor from responsibility for such investigations, interpretations, and proper use of information in preparation of his proposal.

5.5. Minimum Qualifications

To ensure a safe, efficient, high-quality project, the owner should present a list of minimum qualifications to the potential contractors.

These minimum qualifications typically include a minimum number of pipe bursting projects successfully completed by the contractor. The contractor should furnish a list of references where pipe bursting was used in similar ground conditions. Financial data on the contractor and any subcontractors should also be furnished. The deadline for submittal of these qualifications should be clearly specified and should be prior to contract award.

5.6. Minimum Submittal Requirements (from Contractor to Owner)

To ensure compliance with the requirements of the specifications, a number of submittals should be required from the contractor. The specifications should clearly state the minimum submittal requirements for the contractor. The timing of the various submittals should be in accordance with the submittal schedule as presented in the contract. Submittals detailing the construction process, equipment, lubrication fluids, layout, and machinery set-up should be approved by the engineer prior to construction. Other submittals (e.g., as-built construction records) will be submitted throughout the construction process.

5.7. Requirements for Monitoring and Protecting Existing Utilities and Site Features

If of concern, the nearby utilities and structures should be monitored for displacement or damage, and the contract documents should clearly state the monitoring requirements. If the contractor disturbs the surrounding environment, existing utilities, or structures, the contractor should be required to restore them to their original condition.

When necessary, the owner should specify the level of noise, lighting, traffic interruption, and work hours that will be acceptable during construction.

5.8. Measurement and Payment

Ideally, the payment procedure should be fair and easily interpreted by the contractor and the owner. For small jobs or for a small component of larger projects, lump sum contracts are often preferred. However, for most pipe bursting projects, payment by the lineal foot of installed pipe of different diameters and/or upsizing is often preferable. Payment by the lineal foot allows the contractor to price each drive according to degree of difficulty, complexity of the site conditions, and anticipated competition. A combination of lump sum, lineal footage, or time and materials may be applicable when the specified project includes difficult ground conditions.

Special payment items for anticipated potential problems such as local excavations at an obstruction can help prevent arguments about the cost of such items at a later date (see section 5.9). The cost and number of these contingency items must be evaluated carefully to prevent problems with an unbalanced bid.

5.9. Remedial Action Requirements

During the bursting operation, if any obstruction is encountered that can not be burst through, an excavation may need to be made at the location of the obstruction to allow the bursting to continue. In such cases, the contractor should inform the owner or the engineer and ask for direction. The bid documents should address such circumstances so that the contractor is aware, prior to bid, how these problems will be handled, including information on payment (whether the owner will pay on a time and materials basis, a lump sum basis, or whether the situation will be negotiated on a case-by-case basis).

When an adjacent underground utility is damaged, the contractor must immediately notify that utility owner of the location and nature of damage. Also, the contractor must allow the utility owner a reasonable time to accomplish necessary repairs before continuing the bursting. In general, when a correctly marked and specified utility line is struck and damaged, the damage caused by the contractor will be repaired at his/her own expense. For damage to utility lines that are unmarked or incorrectly located, the owner or the other utility provider would be responsible. The accuracy of utility locations and the required clear space should be specified in bid documents provided to bidders.

Most contract documents can not or do not cover all the problems that may occur on a project. The owner and engineer should strive to identify anticipated problems and should establish or request submittals detailing a course of action for the contractor to follow in the event that problems are encountered. These actions should as far as possible cover all anticipated problems.

6. Submittals from Contractor to Owner

6.1. General

Submittals requested by the owner from the contractor are to ensure compliance with the project specifications. In addition, they provide the basis for monitoring details of the project. These submittals, or portions of, can be provided at various points during the procurement and construction process. The submittals of interest will be discussed in this section.

6.2. Material

Submittals should include shop drawings, catalog data, and manufacturers technical data showing complete information on material composition, physical properties, and dimensions of new pipe and fittings. A certificate of compliance with specifications for materials needs to be furnished. Manufacturer's recommendations for handling, storage, and repair of pipe and damaged fittings should also be included.

6.3. Construction Method

Submittals should include method of construction and restoration of existing service connections. This should include detail drawings and written description of the entire construction procedure to install pipe, bypass flow and reconnection to service connections. A methodology statement should explain the operation of the equipment. The submittals should include all details of the equipment including the bursting tool, protective sleeve (if used), and winching unit. If lubricant is planned for the project, the contractor should submit information on the type of lubricant to be used and any environmental implications associated with its use or migration away from the pipe alignment. Submittals should include material safety data sheets (MSDSs) on material, a description of where the material will be used, and the purpose in the construction process.

6.4. Bypassing

The contractor needs to submit information on how the temporary diversion for the pipeline will be provided, and verify that the pumps and by-pass lines shall be of adequate capacity and size to handle all necessary flows during the period the line is out of service. Continuous service of connections to the line during the execution of work is expected to be a responsibility of the contractor, as well as clean-up, repair and property damage cost and claims due to bypassing failures.

6.5. Site Layout

Construction site layout information is important to the owner to verify that the operations do not infringe on personal property or unnecessarily interfere with any public or private operations. A sketch should be submitted indicating storage areas, equipment set-up areas, construction staging areas, and locations of all major supporting equipment.

6.6. Contractor Qualifications

The contractor must provide verification of qualifications to the owner. The contractor should furnish background information on key personnel to allow the owner to ensure they have adequate experience. For prior job references, complete names, affiliations, addresses, and telephone numbers should be furnished so the owner may contact the references to verify satisfactory prior performance. Supporting financial data on the company should also be submitted to ensure that the contractor and pipe supplier will be available to support the product in the long-term.

6.7. Quality Assurance/Control Plan

The submittals should address how the specification requirements on quality control items will be satisfied. Quality control procedures for materials and construction procedures, and methods of performance testing of the finished product should be included. These submittals should clarify the monitoring of quality control over suppliers, manufacturers, products, services, site conditions, and workmanship. When required in individual specifications, a material or product suppliers' or manufacturers' technical representative should be provided to observe site conditions, conditions of surfaces and installation, quality of workmanship, start-up of equipment, operator training, test, adjust, and balance of equipment as applicable, and to initiate operation, as required. If defined in individual specifications, the minimum time requirements for start-up operations and operator training should be met and documented.

The contractor may also be required to verify that the as-replaced condition/performance of the completed pipeline is satisfactory. If television inspection of the replaced line is specified, the contractor is to provide videotape of the entire length of the pipe to show that the line is free of visual defects.

6.8. Safety Plan

The safety plan is to ensure that the public and workers are protected from construction hazards. This safety plan should include a submittal of the contractor's safety procedures for all workers.

6.9. Construction Records

Various submittals are required during the construction process to monitor the project progress, problems encountered and to document the work carried out. These include the following: pre-construction survey reports, documented as-built conditions, construction logs, materials installed, extent and causes of delays, locations of affected areas, and unusual problems or conditions encountered.

7. Conclusions

Pipe bursting represents an effective method for trenchless replacement of existing pipes. The research results discussed have supplemented the experience gained by contractors, manufacturers and public works engineers and have resulted in:

- a greatly improved understanding of the level of vibration and ground movement associated with pipe replacement operations and how these diminish with distance from the burst location
- greater confidence in the technical data underpinning the effect of pipe bursting on surrounding utilities and on the pipe drawn in as a replacement
- identification of some potential problem areas to avoid under particular job site conditions.

As in any underground work, pipe bursting projects should anticipate the potential for changed ground conditions, unlocated adjacent utilities and unrecorded problems with the pipe being replaced. Successful projects require good preplanning, careful observation of job progress and key monitored variables during construction, and equitable cooperation between owner and contractor in dealing with unexpected circumstances.

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Appendix

Sample Technical Specifications for the Reconstruction of Sanitary Sewer by the Pipe Bursting/Replacement Process

1. GENERAL

1.1 DESCRIPTION

This clause includes requirements to rehabilitate existing sanitary sewers by the pipe bursting method. This method involves splitting the existing pipe and immediately installes a new polyethylene pipe reconnecting existing sewer house connections, television inspection of the polyethylene pipe and complete installation in accordance with the Contract documents.

1.2. QUALITY ASSURANCE

A. The Contractor shall be certified by the particular Pipe Bursting System Manufacturer that such firm is licensed installer of their system.

B. Polyethylene pipe jointing shall be performed by personnel trained in the use of thermal butt-fusion equipment and recommended methods for new pipe connections. Personnel directly involved with installing the new pipe shall receive training in the proper methods for handling and installing the polyethylene pipe. Training shall be performed by a qualified representative.

C. The Contractor shall hold the City and Engineer harmless in any legal action resulting from patent infringements.

D. The Contractor shall have a minimum of x years experience using the pipe-bursting method and shall have installed no less than xx thousand feet.

E. The Contractor must have successfully completed at least one (1) job, similar in scope, to the requirements of pipe bursting set forth in these bid documents.

1.3. SUBMITTALS

Submit the following Contractor's Drawings:

1) Shop drawings, catalog data, and manufacturer's technical data showing complete information on material composition, physical properties, and dimensions of new pipe and fittings. Include manufacturer's recommendation for handling, storage, and repair of pipe and fittings damaged.

2) Method of construction and restoration of existing sewer service connections. This shall include:

a. Detail drawings and written description of the entire construction procedure to install pipe, bypass sewage flow and reconnection of sewer service connections.

3) Certification of workmen training for installing pipe.

4) Television inspection reports and video tapes made after new pipe installation.

1.4. DELIVERY. STORAGE. AND HANDLING

A. Transport, handle, and store pipe and fittings as recommended by manufacturer.

B. If new pipe and fittings become damaged before or during installation, it shall be repaired as recommended by the manufacturer or replaced as required by the Engineer at the Contractor1s expense, before proceeding further.

C. Deliver, store and handle other materials as required to prevent damage.

1.5. METHODS FOR NEW PIPE INSTALLATION

The methods approved for rehabilitation of existing sanitary sewers by pipe bursting and installation of new polyethylene pipe are xxx, or prior approved equal.

2. MATERIALS

2.1. Polyethylene Plastic Pipe shall be high density polyethylene pipe and meet the applicable requirements of ASTM F714 Polyethylene (PE) Plastic Pipe (SDR-PR) based on outside diameter, ASTM D1248, ASTM D3550.

A. Sizes of the insertions to be used shall be such to renew the sewer to its original or greater flow capacity.

B. All pipe shall be made of virgin material. No rework except that obtained from the manufacturer's own production of the same formulation shall be used.

C. The liner material shall be manufacture from a High Density High Molecular weight polyethylene compound which conforms to ASTM D- 1248 and meets the requirements for Type III, Class C, Grade P-34, Category 5, and has a PPI rating of PE 3408.

D. The body of the pipe produced from this resin shall have a minimum cell classification of 345444C under ASTM D-3350 and the inner wall shall be Light in color and have a minimum cell classification of 345444E under ASTM D-3350. A higher cell classification limit which gives a desirable higher primary property, per ASTM D-3350 may also be accepted by the Engineer at no extra cost to the owner. The value for the Hydrostatic Design basis shall not be less than 1600 PSI (11.03 MPA) per ASTM D-2837.

E. The polyethylene pipe shall have light colored interior fully bonded and co-extruded pipe structure. The bond between the layers shall be strong and uniform. It shall not be possible to separate and two layers with a probe or point of a knife blade so that the layers separate cleanly at any point, nor shall separation of bond occur, between layers, during testing performed under the requirements of this specification.

F. The pipe shall be homogenous throughout and shall be free of visible cracks, holes, foreign material, blisters, or other deleterious faults.

G. Dimension Ratios: The minimum wall thickness of the polyethylene pipe shall meet the following:

Depth of Cover (Feet)	Minimum SDR of PiQe
0 - 16.0	21
> 16.1	17

H. Material color shall be black on the outside for ultraviolet protection and have 10 mils of a light-colored inner layer for enhanced television inspection.

2.2. TESTS

Tests for compliance with this specification shall be made as specified herein and in accordance with the applicable ASTM Specification. A certificate with this specification shall be furnished, upon request, by the manufacturer for all material furnished under this specification. Polyethylene plastic pipe and fittings may be rejected if they fail to meet any requirements of this specification.

3. SEWER SERVICE CONNECTIONS

3.1. All sewer service connections shall be identified, located and excavated prior to the pipe insertion to expedite reconnection. Upon commencement, pipe insertion shall be continuous and without interruption from one manhole to another, except as approved by the engineer and/or his representative. Upon completion of insertion of the new pipe, the Contractor shall expedite the reconnection of services so as to minimize any inconvenience to the customers.

3.2. Sewer service connections shall be connected to the new pipe by mechanical methods or electrofusion methods. Once the saddle is secured in place, a hole shall be drilled full inside diameter of saddle outlet in pipe liner.

A. Mechanical saddles shall be made of polyethylene pipe compound that meets the requirements of ASTM D1248, Class C, have stainless steel straps and fasteners, neoprene gasket and backup plate. Mechanical saddles shall be Strap-On-Saddle Type as manufactured by Driscopipe or Tapping Saddle manufactured by Fernco Joint Sealer Co., DFW Plastics, Inc. or approved equal.

B. An HDPE branch saddle may be sidewall fused onto the O.D. of the installed HDPE pipe. This may be done with commercially available sidewall Fusion machine or installed with "Unicore" HDPE splice under the base of saddle and heated to pipe O.D.

4. PREPARATION

4.1. BYPASSING SEWAGE

A. By-Pass Pumping: The Contractor, when and where required, shall provide diversion for the pipe bursting/replacement process. The pumps and by-pass lines shall be of adequate capacity and size to handle all flows. All costs for by-pass pumping, required during installation of the pipe shall be subsidiary to the pipe reconstruction item.

B. The Contractor shall be responsible for continuity of sanitary sewer service to each facility connected to the section of sewer during the execution of the work.

C. If sewage backup occurs and enters buildings, the Contractor shall be responsible for clean-up, repair, property damage cost and claims.

4.2. TELEVISION INSPECTION

Television inspection of pipelines shall be performed by experienced personnel trained in locating breaks, obstacles and service connections by closed circuit color television.

Television inspection shall include the following:

A. Video tapes (post) to be submitted to the city before final invoice.

B. Video tapes to remain property of the city; Contractor to retain second copy for his use.

C. All flows tributary to reach of sewer being inspected are to be completely by-passed around the reach during inspection if necessary and required by city.

D. Post construction video tape upon completion of reconstruction of each reach of sewer with the voice description, as appropriate with stationing of services indicated. Data and stationing to be on video.

E. Should any portion of the inspection tapes be of inadequate quality or coverage, as determined by the City the Contractor will have the portion reinspected and video taped at no additional expense to the City.

5. CONSTRUCTION METHODS

5.1. Insertion or launching pits shall only be allowed at locations of existing or proposed manholes, unless otherwise approved by Engineer, to minimize impact on existing trees.

5.2. Equipment used to perform the work shall be located away from buildings so as to lessen the noise impact. Provide silencers or other devices to reduce machine noise as required to meet requirements.

5.3. The Contractor shall install all pulleys, rollers, bumpers, alignment control devices and other equipment required to protect existing manholes, and to protect the pipe from damage during installation. Lubrication may be used as recommended by the manufacturer. Under no circumstances will the pipe be stressed beyond its yield stress.

5.4. The annular space shall be sealed at the manhole. Sealing shall be made with material approved by the Engineer and/or his representative and shall extend a minimum of eight (8) inches into the manhole wall in such a manner as to form smooth, uniform, watertight joint.

5.5. FIELD TESTING

A. After the existing sewer is completely replaced, internal inspection with television camera and video tape shall be carried out as required. The finished tape shall be continuous over the entire length of the sewer between two manholes and be free from visual defects.

B. Defects which may affect the integrity or strength of the pipe in the opinion of the Engineer shall be repaired or the pipe replaced at the Contractor's expense.

6. PIPE JOINING

6.1. The polyethylene pipe shall be assembled and joined at the site using the thermal butt-fusion method to provide a leak proof joint. Threaded or solvent-cement joints and connections are not permitted.

All equipment and procedures used shall be used in strict compliance with the manufacturer's recommendations. Fusing shall be accomplished by personnel certified as fusion technicians by a manufacturer of polyethylene pipe and/or fusing equipment.

6.2. The butt-fused joint shall be properly aligned and shall have uniform roll-back beads resulting from the use of proper temperature and pressure. The joint surfaces shall be smooth. The fused joint shall be watertight and shall have tensile strength equal to that of the pipe. All joints shall be subject to acceptance by the Engineer and/or his representative prior to insertion. All defective joints shall be cut out and replaced at no cost to the City. Any section of the pipe with a gash, blister, abrasion, nick, scar, or other deleterious fault greater in depth than ten percent (10%) of the wall thickness, shall not be used and must be removed from the site. However, a defective area of the pipe may be cut out and the joint fused in accordance with the procedures stated above. In addition, any section of pipe having other defects such as concentrated ridges, discoloration, excessive spot roughness, pitting, variable wall thickness or any other defect of manufacturing or handling as determined by the Engineer and/or his representative shall be discarded and not used.

6.3. Terminal sections of pipe that are joined within the insertion pit shall be connected with a full circle pipe repair clamp. The butt gap between pipe ends shall not exceed one-half (1/2) inch.

7. MEASUREMENT AND PAYMENT

7.1. The inserted pipe shall be paid for per linear foot of the size pipe specified and shall include all pipe bedding, backfill material, annulus sealing material and launching pits. Locating and reconstruction of services and all reconnections of services shall be paid for per each connection made, including fittings and pipe.

7.2. The work performed as prescribed by this item will be paid at the unit price per linear foot of sanitary sewer by pipe bursting/replacement for the specified pipe diameter and location, per each for "Locate, reconstruct and reconnect" for the specified pipe diameter, which price shall be full compensation for the installation of the new pipe, furnishing and placing of all materials, labor, tools, equipment, cleaning, and preparation of the existing pipe to receive the new liner, and any other necessary to complete the project.

7.3. Video inspection of final installed pipe shall be paid based on the cost per linear feet to TV the entire length of new pipe.

7.4. The cost of any necessary by-pass pumping shall be considered subsidiary to the cost of pipe installation and shall not be a separate pay item.

8. WARRANTY

All work performed under this Contract shall be warranted to be free from defects in material and workmanship for a period of one year from the date of acceptance. If the Engineer determines that the process has failed during the warranty period, the Contractor will perform any and all repairs at no additional cost to the Owner.