3.1 GENERAL CONDITION ASSESSMENT

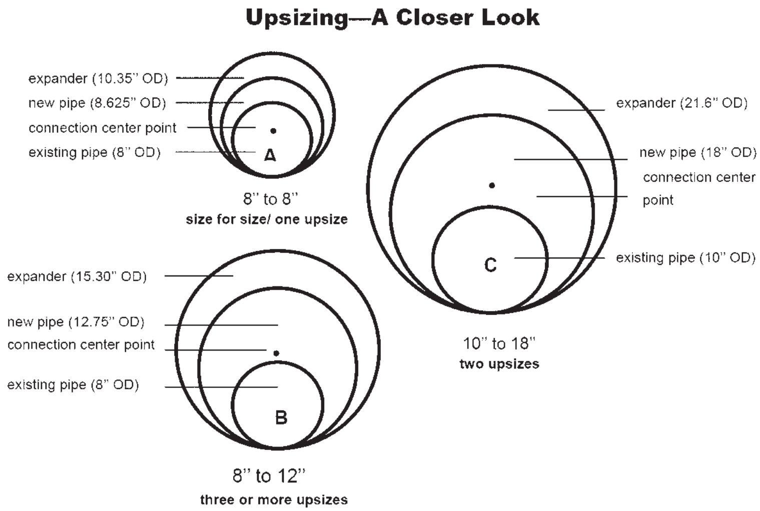
For the existing pipe, the type, material, and associated components (i.e., reinforcement, joint type) have a direct impact on the viability of the bursting/replacement methodology and the design of the expansion cone. Various pipe materials used in both water and wastewater service, and their potential for being burst and replaced using these trenchless technologies, are discussed in detail in Section 3.3.

Once it has been determined that the existing pipe is a candidate for bursting technology, the structural condition, alignment, service connections, and appurtenances must be assessed. Condition assessment generally results in existing piping systems falling into one of two groups: (1) existing piping systems that are in a serviceable condition but are, from a hydraulic perspective, undersized and require upsizing, or (2) piping systems that have some degree of deterioration that inhibits flow, dependability, or both.

3.1.1 Undersized Pipe

Most owners of water and wastewater utilities have hydraulic modeling capabilities for their systems. This is helpful in quickly providing feedback related to the requirements for flow through a given portion of a pipe system. Many of these same modeling programs also maintain information about the size and type of pipes, location, and frequency of repair for the system. Locations are often stored in the owner's geographic information systems (GIS) that can provide nearly exact locations of pipelines, appurtenances, point repairs, and so forth. These owners have the luxury of being able to accurately store information about the locations and alignment of existing facilities and infrastructure as well as import location data from other piping systems.

After the pipeline has been hydraulically analyzed and the conclusion has been reached that a larger line would be needed, consideration of the capabilities of the pipe bursting equipment must now be addressed. The feasibility of upsizing depends on a number of factors, including soil conditions, trench geometry, diameter increase, volume increase, and bursting length (North American Society for Trenchless Technology (NASTT), 2004). Generally, pipe bursting/replacement equipment is capable of increasing the diameter of the new pipe by two nominal sizes (e.g., existing 6-in. pipe may be enlarged to either 8-in. or 10-in. pipe). Although increases larger than two nominal sizes have been successfully completed, the pipe bursting guidelines of the National Association of Sewer Service Companies (NASSCO) consider increases of three nominal sizes to be in the most difficult category. The NASSCO Project Design Classification is provided in Fig. 3-1, designating the three categories of difficulty (A, B, C), with Case A being the least difficult and Case C the most difficult. Appli-



Case	Depth of Pipe	Existing Pipe Diameter	New Pipe Diameter Options	Burst Length
Case A	<12 ft	4" - 12"	Size-for-Size or one (1) nominal upsize	0 - 350 ft
Case B	>12 ft <18 ft	12" - 20"	2 nominal upsizes	350 ft - 450 ft
Case C	>18 ft	20" - 36"	3 or more upsizes	> 450 ft

FIGURE 3-1. NASSCO upsizing guidelines.

cations corresponding to great depth, long burst length, or large diameter also increase the level of difficulty of the pipe bursting operation.

3.1.2 Deteriorated Pipe

Utilities generally have established criteria for determining when a portion of a piping system is deteriorated to the extent that it requires replacement. It is of paramount importance that the suspected deteriorated line be inspected (via CCTV or, alternatively, scanned) to determine the extent of any blockage or structural deficiencies. In addition, statistical information on the frequency of breaks and repairs and the projected cost for maintaining the line based upon the present value of projected future costs would support the decision for replacement.

Pipelines that are designated as structurally deficient include pipe sections with evidence of existing failure, pending failure, or both. In gravity applications, rigid pipes (such as concrete or clay) typically indicate distress from external loads by the relative severity of cracking at the crown or invert on the interior of the pipe. Flexible (low stiffness) pipes typically indicate distress by exceeding allowable deflection or actual collapse (buckling) at the pipe invert. In very aggressive sewer environments (pH = 1 to 4), pipe structural deficiency is likely to be the result of internal corrosion. Sewer mains containing an anaerobic environment (e.g., formation of slimes with no free oxygen, prolonged air spaces, high temperatures, long detention times, low velocities, and formation of high hydrogen sulfide gas concentrations) inside the pipe will likely result in acid-producing bacteria and associated corrosion.

Changes in vertical alignment caused by initial misalignment, poor installation practices (inadequate pipe bedding and backfilling), or differential settlement or flotation are characterized by misaligned joints or swags that may adversely affect the hydraulic performance of gravity pipeline systems. Depending upon the severity of the misalignment or swag, static pipe bursting systems, applied to existing pipes with substantial beam strength (e.g., DIP or VCP) may help to straighten minor alignment variations. If the alignment variations are excessive or abrupt, it is best practice for the owner and engineer to plan for appropriate point repair(s). Longer sags (more than 10 ft) will likely remain in the new replacement line and result in higher maintenance, potential overflows from siltation, loss of capacity, and an increase in hydrogen sulfides. The severity and impact of remaining long sags should be considered by the owner and engineer during the overall project evaluation.

3.2 SPECIAL CONSIDERATIONS

In general, owners and engineers should avoid stating requirements for means and methods for construction operations. Installation specifications should be performance-based. It is, however, important to identify potential obstacles which may limit the applicability of some of the bursting techniques so that appropriate information is available for the purpose of soliciting project bids where the risk to the bidding contractors has been minimized.

It is essential to have information regarding the type and condition of the existing pipe and appurtenances. If the pipeline is being replaced because it is undersized (but is otherwise in good physical condition) and the bursting cone is appropriately designed, the pipe will tend to resist (without collapse) the axial component of the force applied during the bursting operation. If, however, the pipe is being replaced because of deterioration (e.g., internal corrosion, external corrosion, or both) and the deterioration is not uniform through the wall of the pipe, it is possible that the axial force component being transmitted through the pipe wall may collapse and longitudinally telescope the existing pipe. This effect may result in the thinner material accumulating into a thicker, irregularly shaped mass in front of the bursting cone, possibly preventing a successful bursting operation.

Potentially liquefiable soils in wet environments require additional study. Loose, granular, saturated soils have the potential to liquefy from vibrations associated with pipe bursting systems that use percussion to advance the bursting head. This could possibly result in induced dramatic grade deviations, even though the original line had an acceptable grade and alignment. Proper identification of these soil characteristics is necessary to ensure that the most appropriate bursting equipment and materials are used.

In limited construction site space or unusually dense commercial or residential areas, the site restrictions that may impact and limit equipment use, the new product pipe material, and the installation methodology (cartridge or assembled line) should be defined. Access to the site, maximum allowable work area, traffic flows to businesses and residences, restrictions on work hours, and limits on the amount of vibration on adjacent structures are important factors to consider. Considerations for these and other restrictions should be addressed by the owner and engineer during the planning stage.

The most important difference between existing gravity service pipe systems and existing pressure service pipe systems is related to the degree of alignment. This is an important issue when considering pipe bursting/replacement systems that use direct jacking force applied directly to the new pipe to advance the bursting head. In gravity service installations, the vertical and horizontal alignment only changes at manholes, with the intermediate path installed in a relatively straight line. Therefore, direct jacking loads applied to a replacement pipe are more uniformly distributed around the circumference of the pipe's cross section. In contrast, pressure pipelines vary the vertical alignment as necessary to maintain a minimum cover and change horizontal alignment as required, without regard to the degree of straightness or alignment between access points. Direct jacking of the associated replacement pipe, if not fully engaged, places a concentration of stresses that may compromise the safety factor built into the joint. Other specific issues are discussed in the following sections.

3.2.1 In-Line Joints and Appurtenances

As-built drawings, previous inspection and maintenance records, and the knowledge of maintenance personnel about the existing pipe must be researched. In-line appurtenances such as valves in water and sewer force mains, bends, manholes, tees and wyes, and other potential in-line obstructions must be field-verified.

Although bell and spigot steel rings used for joining various pipe types are only occasionally used in gravity pipelines, they are commonly employed in pressure applications. Metallic stiffening rings of various types are also used when connecting PE pipe and appurtenances, creating mechanical joints that rely upon compression of the gasket against the pipe for sealing purposes. These rings may be problematic if the force necessary to split or fracture them is greater than the ability of the soil friction to maintain the axial position of the pipe. When this occurs, it is possible for entire sections of pipe to be pulled or pushed back to the equipment or exit pit. Alternatively, if these rings are not properly slit or expanded, they may collect on the front of the head, resulting in significantly greater resistance or drag, or possibly halting the bursting/replacement operation.

3.2.2 Location and Description of Point Repairs

Due to the variation in capabilities of present-day pipe bursting/replacement equipment, the owner and engineer must identify the locations of all point repairs made to the pipeline section that is being studied for replacement. At each location, the type of repair must be described as accurately as possible and include, as a minimum, the information found in Table 3-1.

The pipe bursting/replacement equipment may be capable of breaking up the existing pipe but not capable of breaking stainless steel repair sleeves, replacement sections of ductile iron, steel pipe, or concrete or reinforced concrete encasement without special cutting heads or other special equipment.

TABLE 3-1. Required Information for Each Previous Point Repair Location

Type	Information Required
Type and size of affected pipe	Type, Diameter
Adjacent pipe condition	Describe
Cause of leak or damage	Describe
Length of repair or replacement	Length
Clamp required, type and size	Type, Diameter, Length
Solid sleeve required, type (CI or DI), and size	Type, Diameter, Length
Pipe required, type and size	Type, Diameter, Length
Solid sleeve required for pipe, type (CI or DI), and size	Type, Diameter, Length
Backfill material	Concrete, Stone, Flowable Fill, Other

It is extremely important to assess the general suitability of the existing pipe to be fractured (or split) and radially displaced outward into the adjacent soil. Pipe materials have different mechanical and performance characteristics that make a particular material appropriate for sewer, water, or other applications; few pipe materials are viable for all functional categories. This section discusses the ability of various pipe materials to be burst/replaced using presently available methods and equipment, recognizing that new technologies will be developed that will overcome current limitations. Pipe materials are therefore divided into three classifications: (1) Fracture and Expand, (2) Split and Expand, and (3) Limited or No Existing Technology, as described in Table 3-2. In addi-

TABLE 3-2. Suitability of Existing Pipe Material for Bursting/Replacement

Pipe Type	Fracture and Expand	Split and Expand	Limited or No Existing Technology	New Replacement
Asbestos cement pipe (ACP)	X	—	—	X
Bar-wrapped concrete cylinder pipe	—	—	X	N.A.
Concrete pipe—reinforced (RCP)	X	—	—	X
Concrete pipe—nonreinforced (CP)	X	—	—	X
Concrete pipe—polymer (PCP)	X	—	—	X
Ductile iron pipe (DIP)	—	X	—	X
Fiberglass pipe (FRP, GRP, RPMP)	—	X	—	X
Gray cast iron pipe (CIP)	X	—	—	N.A.
High-density polyethylene (HDPE)	—	X	—	X
Polyvinyl chloride pipe (PVC)	X	X	—	X
Prestressed concrete cylinder pipe (PCCP)	—	—	X	N.A.
Vitrified clay pipe (VCP)	X	—	—	X

tion, pipe materials that may be used as a new replacement pipe installed by the pipe bursting procedure are identified in the last column.

3.3 FRACTURE AND EXPAND

Existing pipe materials are considered fracturable if the pipe experiences brittle catastrophic failure when subjected to a radial expanding (or tensile) force. In general, fracture and expand pipe materials have mechanical properties which are either very low in tensile yield strengths or have very low elongation characteristics (they are brittle). Pipe materials with these properties are good candidates for pipe bursting. They include ACP, CP, RCP, PCP, VCP, and CIP.

3.3.1 Asbestos Cement Pipe (ACP)

Asbestos cement pipe was widely used in water and, to a lesser degree, in sewer applications in the United States until a controversial U.S. Environmental Protection Agency (EPA) ban in 1989 and a corresponding phase-out plan by 1996. Although the formal ban was lifted in the early 1990s, the phase-out plan has been quite successfully implemented. However, ACP continues to be a prevalent pipe material in many parts of the world today. Designed as a rigid conduit, the class and corresponding wall thickness of the pipe are determined by the combination of internal pressures and external loads. Although ACP is structurally a good candidate for pipe bursting/replacement, the owner and engineer must investigate any federal, state, or local regulations that might prohibit abandoning this pipe material in situ after it is fractured. Some regulations may consider burst asbestos pipe a potential hazard, even when left underground and outside the new pipe.

3.3.2 Concrete Pipe (CP)

Concrete pipe is designed as a rigid conduit where the external earth loads are designed to be transferred through the pipe wall into the soil beneath the pipe. There is a wide variety of concrete pipes available for both pressure and gravity service, including CP (also known as Packerhead pipe), RCP (C76), PCCP, RCCP, bar-wrapped steel cylinder, and PCP.

Concrete material has a relatively high compressive strength but an inherently low tensile strength (i.e., its strength in tension is only about 10% of its compressive strength). Thus, standard CP is ideally suited for the pipe bursting/replacement process, during which the bursting cone generates tensile stresses within the walls of the pipe, causing fracture of the existing pipe.

RCP and other pressure cylinder pipes, however, incorporate a steel reinforcing cage or solid steel cylinders on the inside of the pipe for addressing loading conditions requiring a significant increase in tensile capability (e.g., relatively large pipe diameter, increases in burial depth, or both). This steel reinforcing cage restricts the number of bursting systems that can be used for replacing this type of pipe.

PCP was introduced into the United States circa 1997. Polymer concrete uses thermosetting polyester resins and select aggregate only. Mechanical properties for polymer concrete exceed those for Portland cement concrete. However, similar to standard nonreinforced pipe, PCP can be burst/replaced due to its relatively low tensile strength and limited ductility.

3.3.3 Gray Cast Iron Pipe (CIP)

With the exception of gray cast iron soil pipe for architectural applications, CIP is no longer available for use in pressure pipes. CIP, the predecessor of modern-day DIP, was designed as a rigid conduit due to the material's lack of flexibility. This low degree of flexibility allows the relatively brittle CIP to be effectively burst and replaced. CIP typically breaks off in slabs which, in yielding soil trenches where the fragments can be properly expanded, do not normally tend to damage the new plastic pipe during the pull-in replacement process (additional discussion in Section 4.4.1.1). Scratching or gouging is generally not a concern for long-term performance of pipes other than plastic pipes (e.g., HDPE and PVC).

3.3.4 Vitrified Clay Pipe (VCP)

Vitrified clay pipe is one of the most inherently inert pipe materials available (i.e., it is resistant to a broader range of pH values and contaminants than any other pipe material). Because it displays excellent compression strength and poor tension characteristics, VCP is also designed as a rigid conduit. The manufacturing process for VCP prohibits the use of secondary steel reinforcement which, in combination with the relatively low tensile strength and lack of ductility of this ceramic pipe, renders this material the ideal candidate for pipe bursting/replacement. Similar to CIP, VCP generally breaks off in slabs which, in yielding soil trenches where the existing pipe fragments can be properly expanded, do not normally tend to damage new plastic pipes during the replacement process. Once again, scratching or gouging is generally not a concern for long-term performance of pipes other than plastic pipes (e.g., HDPE and PVC).

3.4 SPLIT AND EXPAND

Existing pipe materials that are not considered to be brittle have mechanical properties consistent with either high tensile strength or moderate ductility (as measured by the material percent elongation during a tensile test), or relatively low tensile strengths with extreme high ductility (elongation). Such materials are unlikely to be expanded sufficiently to allow the required clearance for the trailing replacement pipe. Systems have therefore been developed that operate in two stages. In the first stage, the pipe is slit, splitting the pipe longitudinally. The required tool is typically configured with a series of successively larger hardened disk cutters, aligned along the cutter's long axis; hydraulically activated cutting blades; or hardened or carbide-tipped cutting wings. During the second stage, a cone-shaped expanding head, either integral to the splitting tool or immediately behind it, forcibly expands the existing pipe into the adjacent soil to generate adequate clearance for the trailing replacement pipe.

Replacement of DIP or steel pipes, using the process of split and expand, requires a substantial amount of axial thrust to expand the slit pipes. In general, this method for pipe replacement is limited to static pull or push systems.

3.4.1 Metallic Pipe

Existing metallic pipes for sewer applications will generally include DIP and, in some systems, steel pipe, both smooth-wall and corrugated. Both materials have approximately the same mechanical properties. With a minimum tensile strength of 60,000 psi and a minimum elongation of 10%, metallic pipes are clearly some of the most difficult to burst/replaced. Furthermore, there is the possibility that the axial slit/split, cut into the wall of either DIP or steel pipe prior to the expansion, may present sharp edges to the replacement pipe. When attempting a large upsizing, this condition may detract from the long-term performance of plastic pipe due to external scouring, cutting, or gouging of the pipe wall. Such external damage would have a much greater impact on plastic pressure pipe than on plastic gravity service piping applications. In order to reduce such occurrences, the pipe burst operation should be limited to size-on-size or to an increase of only one nominal size.

Similarly, when bursting existing pipe installed in an environment that has been determined to be corrosive to metallic pipes, any new steel replacement pipe with an exterior bonded coating system for corrosion protection can be compromised by scoring, cutting, or gouging of the protective coating. However, there are corrosion protection methods available which are appropriate for some types of metallic pipe installed by the pipe bursting method. These methods may require that the pipeline be either welded or, for rubber-gasketed joints, utilize some type of joint bonding to provide electrical continuity. This continuity allows the pipeline to be monitored for the development of active corrosion cells. At any time during the life of the pipeline, as indicated by changes in the pipe–soil potential, life-extending cathodic protection can be added (related discussion in Section 4.3.2.).

3.4.2 Plastic Pipe

Plastic pipes of interest include fiberglass, HDPE, and PVC. Filament-wound fiberglass pipe can have tensile strengths on the same order of magnitude as metallic pipes. Therefore, these pipes typically require the process of slitting/splitting prior to expanding. However, random-oriented fiberglass pipe, such as reinforced plastic mortar pipe, may be burst by expansion. Due to their high ductility characteristics, existing HDPE and PVC pipes also require slitting/splitting prior to replacement.

3.4.3 Limited or No Existing Technology

Two types of concrete pressure pipe manufactured using multiple components are not economically feasible to burst using existing technologies. These include prestressed concrete pipe (both with and without a steel cylinder) and bar-wrapped concrete cylinder pipe. Historically, the smallest-sized pipes for these materials have been 16-in. and 12-in., respectively, with the basic structure of the pipe being concrete (with or without steel cylinders) with secondary wraps of either high-strength prestressing wire or mild steel rod. It is this combination of a steel cylinder with wire or rod that prevents present technologies from successfully bursting/replacement such pipes.