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APPLICATION OF TRENCHLESS TECHNOLOGY AT ARMY INSTALLATIONS

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APPLICATION OF TRENCHLESS TECHNOLOGY AT ARMY INSTALLATIONS

1. Purpose. This Public Works Technical Bulletin (PWTB) summarizes information on the use of trenchless technology at Army installations with a primary focus on water and sewer utilities.

2. Applicability. This PWTB applies to all U.S. Army Public Works activities responsible for construction, operation, and maintenance of water and sewer lines.

3. References.

a. AR 420-10, Facilities Engineering: Management of Installation Directorates of Public Works, 15 April 1997, or latest revision.

b. AR 420-49, Facilities Engineering: Utility Services, 28 April 1997, or latest revision.

c. British Technology Moves to North America, *Public Works,* October 1996, p 41.

4. Discussion.

a. The intent of this document is to assist the Director of Public Works (DPW) in providing safe, efficient, and life cycle cost effective utility services in accordance with paragraph 1-4.f.(1) of AR 420-49. The Director of the U.S. Army Corps of Engineers Installation Support Center (CEISC) will provide technical support information and guidance to major commands and installations in accordance with AR 420-10,.para 1-4.d.(3)

b. Trenchless utility piping construction and rehabilitation is potentially more cost effective than open trench methods. In addition, the use of trenchless, rather than open trench construction and rehabilitation methods, may enhance the safety of the workers and the general public while minimizing surface disruption, noise, dust, and adverse environment or economic impacts.

5. Points of Contact. All questions and/or comments regarding this subject that cannot be resolved at the installation or MACOM level should be directed to: US Army Corps of Engineers, CEMP-RI, 441 G Street, NW, Washington, DC, 20314-1000; or: US Army Construction Engineering Research Laboratories at 1-800-USA-CERL, ext. 5590, FAX (217) 398-5564, for Richard Scholze (e-mail: r-scholze@cecer.army.mil).

FOR THE DIRECTOR:

/S/
FRANK J. SCHMID, P.E.
Director of Engineering

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APPLICATION OF TRENCHLESS TECHNOLOGY AT ARMY INSTALLATIONS

Approved for Public Release

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REPORT

APPLICATION OF TRENCHLESS TECHNOLOGY AT ARMY INSTALLATIONS

1. Introduction.

a. This document describes several different types of technologies used in trenchless construction and/or rehabilitation of existing underground utility pipes. The goal is to familiarize the reader with the technology, terminology, and the pros and cons of using specific trenchless technologies in a given application. This is a new field. The technologies and the terminology describing those technologies are changing. Some agencies or contractors may interchange some of the terms presented here. In addition, actual practice in the field may combine one or more of these technologies in a given application.

b. This document will focus on the use of trenchless technologies as applied to the "wet utilities" (water, sanitary sewer, and storm sewer). However, most of the techniques and concepts discussed are equally applicable to other underground utilities, e.g., natural gas, electric, and telecommunications.

2. References. References cited in this report are listed in Appendix A.

3. Reasons for infrastructure rehabilitation.

a. Underground utilities are often neglected. They are out of sight and (usually) out of mind. Frequent inspections are not feasible. Often the utility must fail before it is inspected, repaired, and/or replaced. For example, to avoid catastrophic failures, maintenance personnel should be aware of, and look for the common signs of aging sewer pipes (Koerner 1996):

- Excessive leakage at joints and connections.
- Movement of the pipe bedding due to instability or subsidence.
- External deterioration caused by aggressive environment.
- Mechanical wear on internal surfaces.
- Internal corrosion due to corrosive wastewaters.
- Structural instability.
- Tree root penetration and growth.
- Long-term sediment build up.

b. Another major problem is that underground repairs are often done in response to some sort of major failure or crisis. This situation does not lend itself to well thought out, optimal replacement strategies.

4. Disadvantages of traditional open trench methods.

a. The traditional open trench method involves excavation, pipe removal, pipe replacement, back filling, and site restoration. The excavation pit usually requires sheeting and shoring. Pumping may be required in areas with a high water table.

b. Underground utilities are naturally concentrated in locations with high population and/or high economic activity. Using open trench methods to install or repair underground utilities will invariably cause disruption to normal activities. Traffic maybe detoured or blocked, surface operations may be interrupted, and an open trench itself presents a danger.

c. In one case study in California (Pilecki 1994), a new 25,000 ft long sewer interceptor had to be constructed. The proposed alignment ran near residential areas, two shopping centers, a junior college, a high school, two junior high schools, an elementary school, and a busy arterial street. Clearly, along at least some sections of the alignment, open trench construction would just not be feasible.

d. In another case (City of Mankato, MN 1996), a damaged storm sewer was buried 15 ft underground. Its path ran under railroad tracks and a depot, a four lane road, a ramp for a large parking garage, and many other utilities. The area also has a high water table that necessitates sheeting and dewatering for any excavation. Under these conditions, open trench construction was nearly impossible. The physical and economic constraints called for implementing a trenchless method.

5. Introduction to trenchless technology.

a. Trenchless methods offer several potential advantages. They can reduce noise, dust, construction vibration, and other environmental impacts. Trenchless methods have minimal impact on economic activity in congested areas. Traffic is not interrupted, and other utilities are minimally affected. Trenchless technologies are also generally safer both for the construction workers and the general public.

b. In general, trenchless technologies offer the following advantages (Koerner 1996):

(1) Excavation is not necessary between access points. Sometimes existing manholes can provide sufficient access.

(2) Usually the limited amount of "construction activity" is concentrated at the access sites, rather than along the entire length of the pipeline.

(3) Work can proceed around the clock because trenchless methods are generally quiet and nondisruptive.

(4) Rehabilitated systems can outperform original pipes in terms of strength and flow capacity.

6. Trenchless methods in new construction.

a. This section lists the different methods of trenchless technologies used in construction. Note that the subcategories under pipe jacking and utility tunneling are the same. These two methods are differentiated by the size and type of the pipe used (Tanwani 1994):

- Horizontal Earth Boring
  - Auger boring
  - Compaction
  - Pipe ramming
  - Water jetting
  - Microtunneling
  - Directional drilling
- Pipe Jacking / Utility Tunneling
  - Hand mining
  - Open face shield
  - Tunnel boring machines.

b. In horizontal earth boring, the bore hole is excavated by strictly mechanical means, including removing the spoils, etc. Pipe jacking and utility tunneling require workers inside the pipe or tunnel at least part of the time.

7. Horizontal earth boring.

a. Auger Boring.

(1) Auger boring involves jacking a pipe through the soil with a hydraulic ram. A cutting head is fixed to the leading edge of the pipe. A large auger (nearly the diameter of the pipe) runs the length of the pipe and connects the cutting head to the power source that turns both the auger and the cutting head. The auger transports spoils from the cutting head back to the bore pit.

(2) Two types of auger boring are common: track type (Figure 1) and cradle type (Figure 2). In track type boring, construction of the bore pit is very important. A level concrete floor must be poured, as well as a concrete backstop to counteract the force of the hydraulic ram. The alignment and grade must be carefully monitored during the installation process. The initial alignment of cutting head and pipe are critical to ensure a straight bore. In the middle of the bore, the cutting head is slightly steerable.

Figure 1. Auger Boring Machine (Kramer 1992).

(3) The main boring machine sits on special tracks on the concrete floor, which allow it to slide forward as the hydraulic rams extend. Once started, the boring is a cyclical process; one length of pipe and section of auger are inserted at a time.

(4) In a cradle type auger bore, the bore pit setup is not as critical. The boring machine and auger system are entirely suspended by a crane. The advantage to this method is that much preparatory work can be done at the surface. Usually, the entire length of pipe and auger are preassembled at the surface and then lowered into position. A jacking lug, or "dead man," must be installed at the bore pit to provide reaction force to a winch, which pulls the assembly forward into the bore.

Figure 2. Cradle Type Boring Machine.

b. Compaction.

(1) This method forms a bore hole by displacing the soil radially outward rather than removing spoil as in the auger method. Compaction can only be used for smaller pipe installations, i.e., with a diameter less than 6 in.

(2) The first type of compaction is the rod pusher. This machine pushes or pulls a solid rod through the soil by hydraulic force, simply displacing the soil. To further enlarge the hole, the machine can pull a reamer back through the hole. Rods are usually about 4 ft in length and can be linked in series to achieve the desired bore length.

(3) The rotary compaction method is similar to the rod pusher, however, the rod used is similar to a drill bit. It is rotated as it is forced horizontally through the soil.

(4) The percussive compaction method uses a self-propelled tool (Figure 3) powered by air or hydraulic pressure through a flexible line leading back to the bore pit. The pressure lines power a reciprocating cylinder in the head of the boring tool. Although this method will work in a wide range of soil conditions, the rate of advance depends heavily on soil type. The maximum speed of the boring tool is about 4 ft/minute.

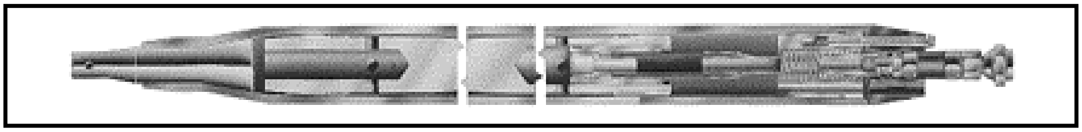

Figure 3. Pneumatic Mole Device.

c. Pipe ramming.

(1) The pipe ramming method uses the pipe intended for installation as the driving tool to displace soil, creating its own bore hole. A hydraulic or compressed air power source hammers at the trailing end of the pipe. Because of this force, only steel pipe may be used.

(2) The leading end of the pipe is covered with a projectile shaped cutting tool. The leading end is also banded to increase strength and to form a slightly larger bore to reduce friction on the following sections. It is also possible to leave the leading end of the pipe open and remove soil from the interior of the pipe as it is driven forward. A slurry of water and bentonite may be applied to the leading end and outer edge to help reduce friction.

d. Water Jetting. Water jetting, as the name implies, relies on a high speed jet of water to liquefy and remove soil. A special nozzle is attached to the end of a solid rod and extended forward into the bore hole. Additional bore depth is accomplished by adding rods to further extend the nozzle into the bore. This method is rather simple and does not require specialized equipment. However, disadvantages include poor control of overcut, disposal of large quantities of water and muck, and the possibility of ground settlement.

e. Microtunneling

(1) Microtunneling (Figure 4) is a subset of horizontal earth boring, which uses highly sophisticated guidance systems and remote control devices to provide extremely accurate directional control. Microtunneling is usually applied to pipelines less than 36 in. in diameter. However, the minimum practical diameter is about 14 in. because there must be enough room for slurry pipes, hydraulic hose, and the guidance system.

(2) The basic principles of microtunneling are similar to other methods discussed in this section. A pipe is jacked into place with hydraulic rams. A reaction wall must be constructed in the bore pit. A jacking (bore) and receiving pit is required for each underground length installed. It is possible for these pits to later serve as manholes. The minimum size of a bore pit is the length of one pipe segment plus 1 meter.

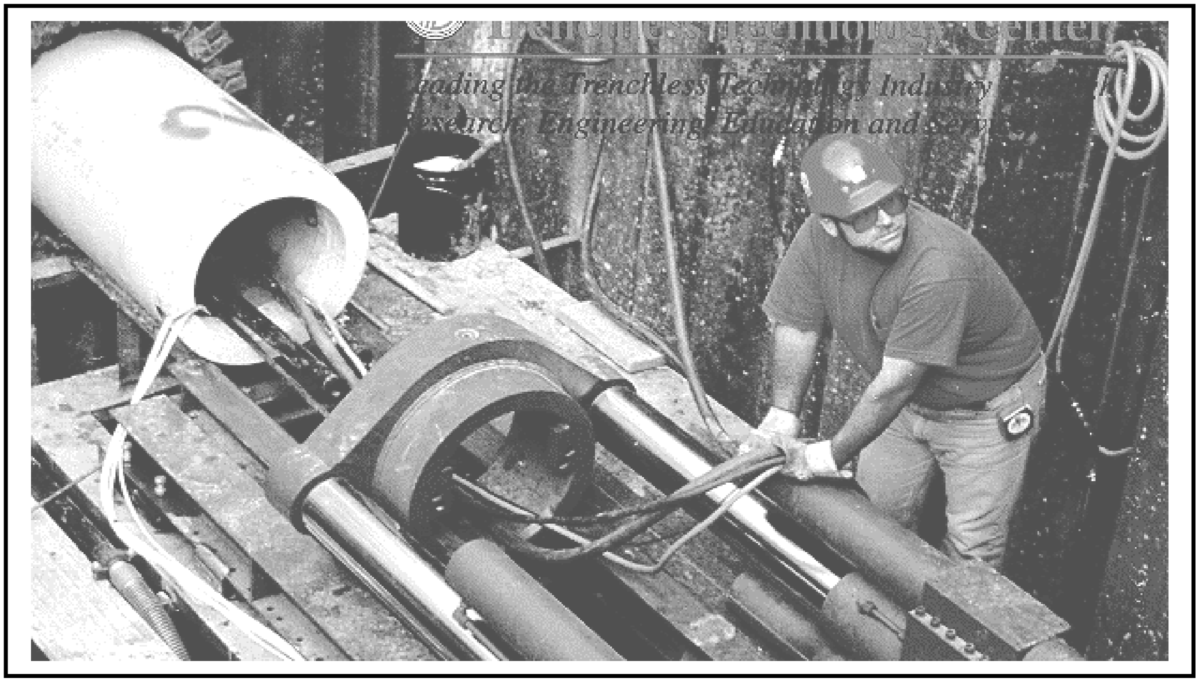

Figure 4. Microtunneling Equipment in Pit.

(3) A cutting head at the leading edge of the pipe can make some directional adjustments. A slurry is pumped to the cutting head for lubrication. Spoil is removed either by an interior auger or by the flow of slurry back to the bore pit. The slurry is actually controlled in a closed system. Two tanks are required at the surface of the job site (a supply tank, and a tank to collect slurry return and to act as a settling basin). Once the cutting head reaches the receiving pit, it is lifted out by crane.

(4) The bore alignment is controlled by a laser guidance system.

(5) A typical microtunnel project (Swallow 1995) used a six worker crew. One worker remotely operated the cutting head and other equipment, two connected pipe sections in the pit, two operated a crane lowering pipe sections into the pit, and one delivered pipe sections to the pit.

(6) The advantages of the microtunneling method are that: (1) the bores are extremely accurate, (2) slurry is contained, and (3) workers are required in the pit only minimally. This final advantage enhances job safety. The major disadvantage of microtunneling is the high capital cost of the equipment. However, the costs may be justified when used in projects that demand high accuracy, or in projects done in especially sensitive areas.

f. Directional drilling.

(1) Directional drilling technology (Figures 5 and 6) is derived from the oil industry and is widely used for crossing under railways, rivers, and roads. It is a two-step process. First, a small diameter pilot hole is drilled the entire length of the proposed pipeline. The drill string enters the ground at an optimal angle of 12 degrees. The rotating drill bit is at the end of the string, or “stem.” Behind the bit, the drill motor is powered by bentonite slurry, which is

pumped through the drill string from the bore entrance. The slurry powers the bit, acts as a lubricant, and helps force the spoil back to the surface.

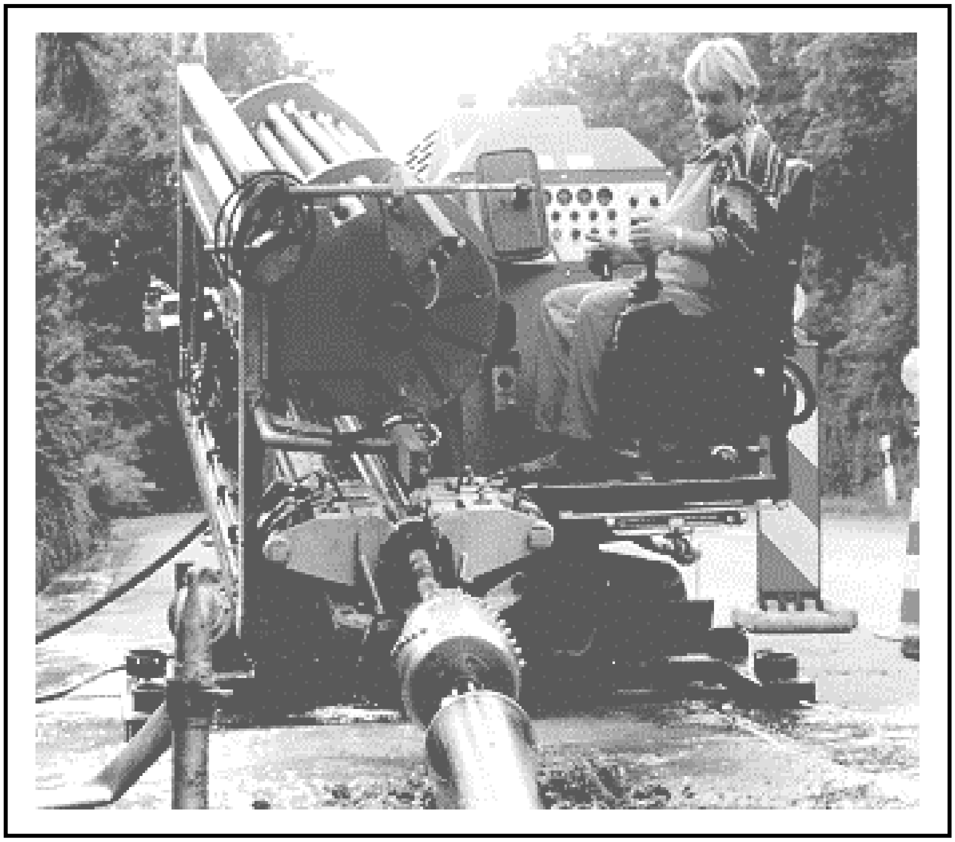

Figure 5. Directional Drill Rig.

(2) The drill stem has a diameter of about 3 in. and does not rotate. One section of the stem, the “bent housing,” is bent at a slight angle. The direction of the drilling is controlled and monitored by the orientation of the bent housing.

(3) An access pit is required about every 400 ft. The pit is used to retrieve the drill head and to make connections.

(4) After the pilot hole is complete over the entire length of the proposed pipeline, the drill string is retracted. A series of reaming tools is then dragged through the bore to enlarge it to the desired diameter. Finally, the pipe to be installed is pulled through the enlarged bore. Steel pipe is almost always used because it can withstand the high tensile stress applied to get the pipe through the bore. In some cases, high density polyethylene may be used.

Figure 6. Directional Drill Rig On Mobile Tracked Platform.

(5) In addition to traditional construction projects, direction drilling can be used for landfill drainage and soil remediation projects. Because soil and groundwater contamination often spread horizontally, the ability to drill horizontal wells for pumping and treating, or other remediation technology, could be very helpful.

8. Pipe Jacking. Pipe jacking is a term used to describe the technique of installing man-entry-size pipes by adding sections of pipe at the drive pit, and jacking the line forward to form the tunnel lining behind the cutting shield.

a. The pipe jacking method can be divided into three areas: (1) the face, (2) the line, and (3) the jacking equipment and setup (Figure 7).

(1) The face. A shield or cutting edge is fitted to the leading edge of a pipe jack. This shield provides the following functions: temporary support to the soil, a hard-faced cutting edge, a safe place for working, a mounting for cutting equipment, a mounting for face-stabilization equipment, a location for monitoring, and a means of adjusting directional attitude. Shields vary widely and choice should be based on ground conditions and water table. Figure 8 shows an example of a conventional shield that allows direct access to the face or immediately behind the face cutters.

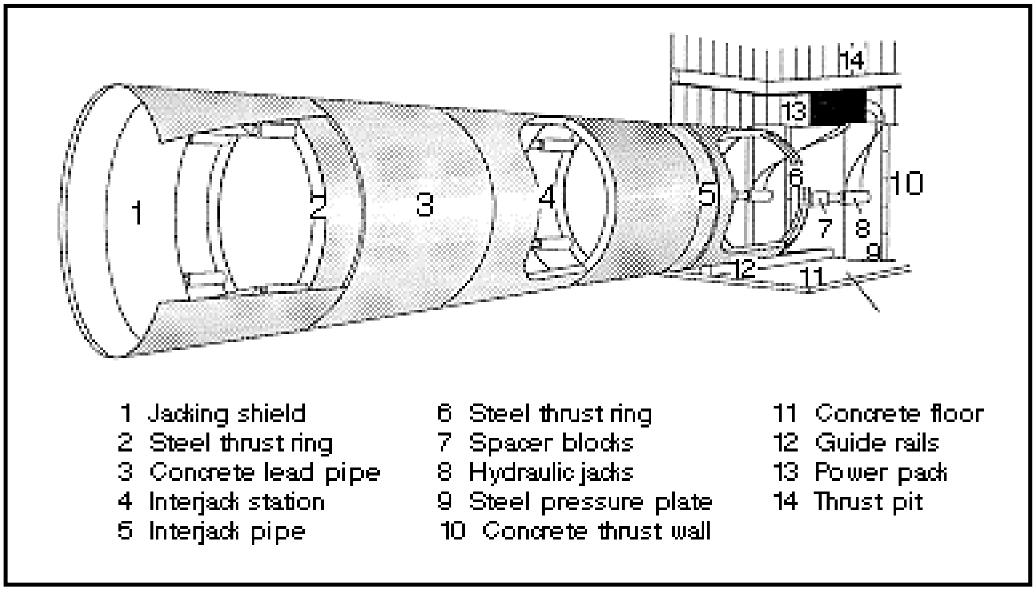

Figure 7. Elements of Pipe Jacking System (Kramer 1992).

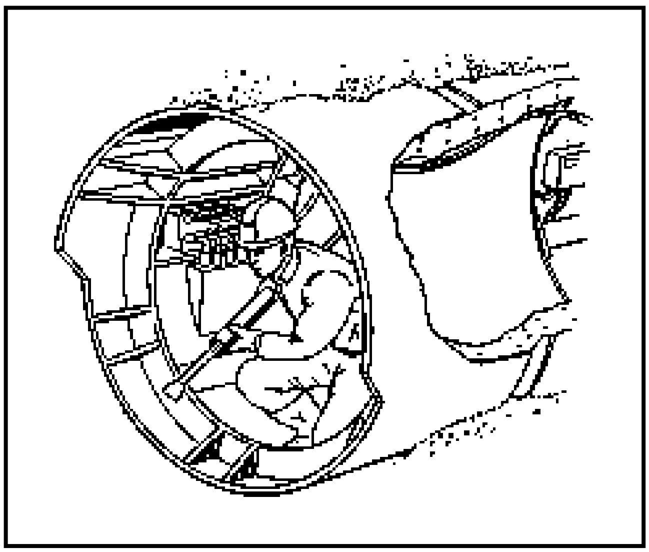

Figure 8. Conventional Open-Manual Shield (Kramer 1992).

(2) The line. The pipes and casings, which are pushed to form the lining are: (1) single pass system, in which the pipe driven becomes the permanent lining; (2) double pass system, in which a temporary casing is first installed and then jacked out by the permanent pipes; and (3) casing system, in which the permanent pipe is laid within the outer duct and usually the annular space is filled. The double pass and casing systems are rarely used, the latter primarily for crossing work, particularly under railways.

(3) Jacking equipment and setup. The essential parts of the jacking rig consist of a set of rams (usually hydraulic); a means of transferring the load uniformly onto the end of the pipe; and a reaction element, usually a block, anchor, or tie. Equipment has to be present to remove the spoil and lower in new pipe sections.

(4) Pipe jacking has become an established construction technique for installing pipes and sleeves of diameters of 36 in. or more. often, this is the most economic choice at depths of over 20 ft. The greatest volume of work is in direct installation of new sewer lines.

9. Trenchless methods for rehabilitation.

a. Coatings.

(1) The purpose of a coating is to repair cracks in the original pipe, or to protect it from corrosive wastewaters or mechanical abrasion.

(2) A coating is either applied to the interior of the deteriorated pipe manually, or with specialized equipment. Manually coating applications can only be done in pipes with a diameter large enough to accommodate the worker, usually a minimum of 48 in.

(3) Coatings are applied by spray, brush, trowel, or roller. Coatings must be applied to a clean, dry surface. Therefore, they must be applied above the waterline, or (if applied below the pipe's waterline) the flow must be diverted until the coating cures. A smaller pipe running through the center of the original pipe can serve as a bypass.

(4) A significant advantage of coating technology is that no extra work or equipment is necessary to make connections at laterals or manholes. Figure 9 shows a mechanized coating application.

b. Cement Mortar. Cement mortar coatings can be applied to concrete, steel, or iron pipes, and can extend the service life of a pipe by up to 50 years. The coating is made of one part sulfate resistant cement to two parts sand. The coating is applied by hand or by an automated spreading machine. Cement mortar cannot be applied in pipe networks with many bends, or in very cold regions.

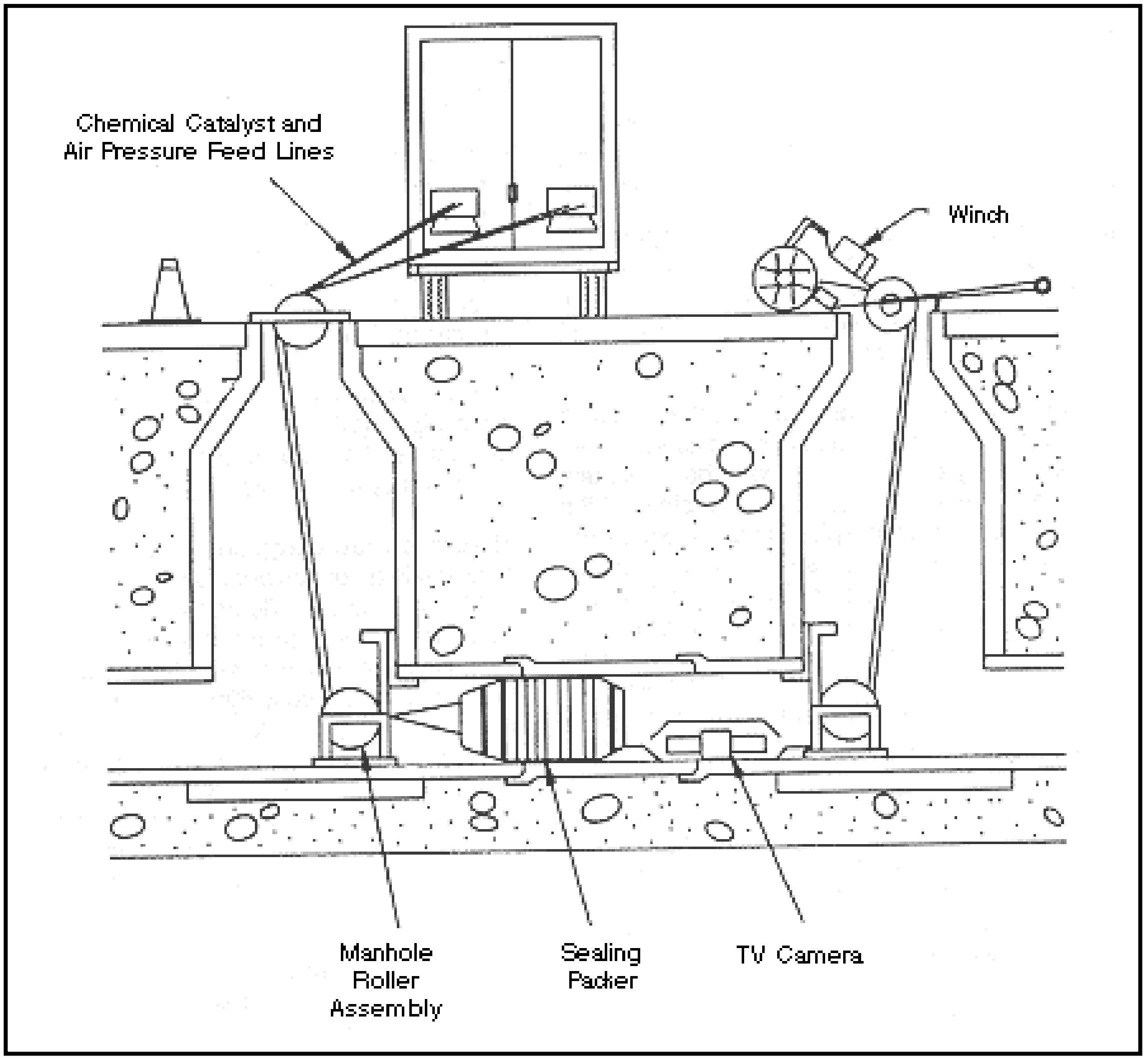

Figure 9. Diagram of Mechanized Coating Operation (USEPA 1991).

c. Reinforced Gunite.

(1) Gunite is also referred to as "shotcrete," and is a mixture of cement, sand, and water. Steel reinforcing mesh or lattice is attached to the interior of the original pipe. Gunite is manually applied with a pressure sprayer to the mesh or lattice. This method improves the structural integrity of the system and can be used on varying cross sectional profiles.

(2) Installing gunite will significantly reduce the internal diameter of the original pipe. However, the smooth surface typical of gunite will reduce the coefficient of friction of the pipe and may actually allow more flow. Increased flow following application of gunite is particularly prevalent in piping that is severely corroded or tuberculated. Therefore, pipelines should be assessed for the impact of reducing the diameter before selecting this coating.

(3) The application of reinforced gunite is restricted to pipes large enough for worker access, usually greater than 4 ft in diameter. The original pipe must be thoroughly clean and dry. The system flow must be completely shut down or bypassed for an extended period.

d. Resin. Resin coatings are made of specialized formulations of polyurethane or phenolic epoxy. They can solve problems of corrosion and erosion. Resins can be applied to steel or concrete pipes, and have excellent adhesion and impermeability.

e. Grout. Grout is actually a variety of materials used to fill voids, stabilize soil, hold bricks in place, coat cement, and prevent infiltration. Grouts are applied under pressure after the pipe has been adequately cleaned to provide a good work surface. A typical grouting application in new construction is to seal the joints between segmented concrete pipe. A common use in rehabilitation is to seal off groundwater infiltration in nonpressure pipelines. Since grouting can be placed wet, it adapts well to irregular surface. Table 1 lists limitations and advantages of grouting.

Table 1

Limitations and Advantages of Grout

Limitations	Advantages
Not a structural repair	Stops groundwater from leaking in
Requires highly skilled operators	Stabilizes soil
Difficult to seal actively infiltrating joints	Fills void around pipe
Packer will not seal properly in badly corroded pipe	Is a long-term, inexpensive trenchless technology
Not for small- or large-diameter pipe	Well suited to 10- to 15-in. pipe
Can make small cracks bigger	
Pipe must be thoroughly cleaned and in good condition (no protruding taps or broken sections)	

(1) The most common grouts available are made of acrylamide gel, acrylic gel, acrylate gel, urethane gel, and polyurethane foam. The difference between grouts is largely due to reaction times. Shorter gel times are better suited for actively leaking joints. Some grouts use a chemical catalyst; others use groundwater to trigger the chemical reaction.

(2) Cementatious grouts are injected through leaky joints to minimize infiltration. Chemical grouts are used to seal minor leaks and cracks. Chemical grout is not a structural repair, but is used to stabilize surrounding soil and prevent groundwater infiltration. Water-activated chemical grout is pushed out of the pipe through joints and small cracks. It sets up outside the affected joint and plugs the gap.

f. Slip lining.

(1) Slip lining is a trenchless rehabilitation method in which a flexible pipe of slightly smaller diameter is slid through an existing pipe. Slip lining is often used in situations where the existing pipe has minor structural problems or corrosion. However, the pipe must have enough structural strength to withstand the force of insertion.

(2) Liners usually drop down one pipe size from the original pipe. Any physical loss of capacity is offset by the lower coefficient of friction that new plastic has over old, rough, cracked pipes. The ultimate flow capacity required of a pipe must be carefully considered. The feasibility of sliplining is greatly affected by the conditions of the original pipe.

(3) Deteriorated original pipes may be slightly out of round, and are likely to have offset joints and heavy mineral deposits. this will affect the size and condition of the annular space. A significant difference in trenchless technologies involves the annular space. Some technologies have large annulus, some are small, some are tight fitting, and some have no space at all. Some new product pipes derive much of their strength from the old pipe. Other technologies use strong, standalone pipes.

(4) Materials used for slip lining include high density polyethylene, polypropylene, fiberglass-reinforced polyesters, reinforced thermosetting resins, and polyvinyl chloride. Of these, high density polyethylene (HDPE) is most widely used because it is flexible, strong enough to withstand the tensile and compressive forces encountered through installation, and resistant to corrosion. HDPE is often the material of choice because it can be joined into a very long, continuous pipe. The pipe ends are melted and held together, making an extremely strong "butt fusion" joint that can withstand the stress of winching.

(5) Slip lining is one form of trenchless technology that does not require that the existing flow in the old pipe be diverted during installation. In fact, flow may help to position the new pipe and act as a lubricant for pushing or pulling the new pipe in place.

g. Push and pull installation.

(1) The push method of slip lining is used when the pipe to be installed comes in segments. The first segment is pushed into place (inside the old pipe) with a hydraulic ram. Then the ram backs up, and the second pipe section is pushed into place, mating with the first pipe section and forcing it one pipe length forward into the old pipe. With the push technique, the access pit at the pipe entrance must be equal in length to one section of new pipe, plus whatever space is needed for the hydraulic equipment. This method is usually applied to larger diameter pipes.

(2) The pull technique (Figure 10), in contrast, is usually used with smaller diameter pipes. The entire length of new pipe to be installed is welded together at ground level before pulling begins. A cable is run from the exit to the entrance point, where it is firmly attached with a special collar to the leading end of the new pipe. Then the new pipe is pulled into place inside the old pipe with a winch. Construction of en entrance and exit pits may not be necessary. Existing manholes may provide adequate access.

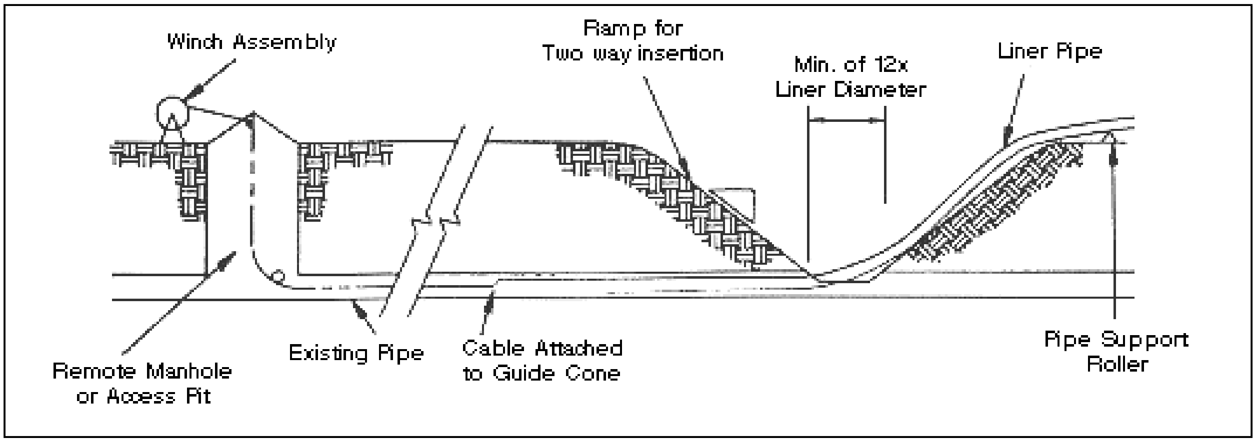

Figure 10. Pull Insertion Technique (USEPA 1991).

(3) With either the push or pull method, the annular space between the old and new pipe must be filled with pea gravel, grout, or some other material. Grout is preferred at manhole intersections to minimize infiltration. This anchors the new pipe and provides for continuous transmission of ground pressures from the earth, through the old pipe, to the new. Having the new pipe anchored will ease the installation of branch connections.

h. Pipe Bursting.

(1) Pipe bursting technology was developed by the British Gas corporation to replace aging natural gas pipelines. This technology is a good choice where existing line and grade are adequate, but the original pipe is deteriorating or too small. Pipe bursting has spread to the United States and been adapted for use with cast iron, concrete, clay, or any other breakable pipeline material.

(2) The pipebursting head is a large, bullet-shaped object that is dragged through the old pipe by a powerful winch (Figure 11). The head forces the walls of the old pipe outward, cracking it into fragments, leaving a void larger in diameter than the original pipe (Figure 12). The new replacement pipe is attached to the trailing end of the bursting head and is pulled into the voided space. (This is similar to the pull method described above).

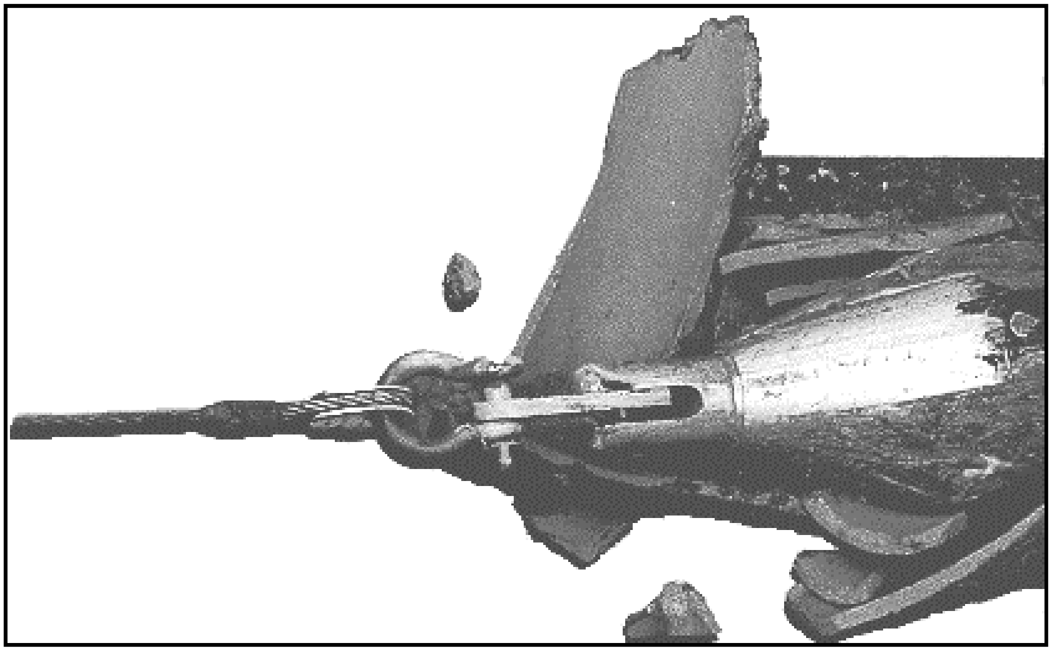

Figure 11. Close Up Pipebursting Head.

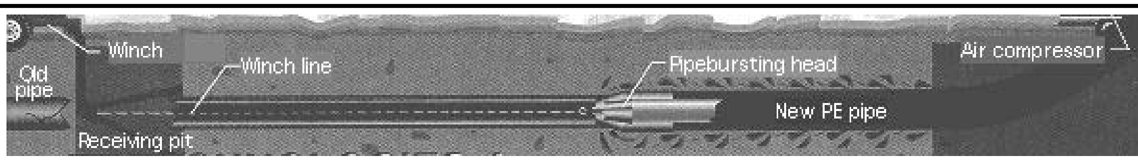

Figure 12. Diagram of Pipebursting Operation.

(3) Three types of pipebursting heads are in common use. The static head is simply a solid object that crushes the pipe through the force of the winch. The static head is suitable for use in soft soils and lightweight pipes. The pneumatic head uses pulsed air pressure to force the head forward. It is used for hard soils and larger diameter pipes. The hydraulic head uses hydraulic pressure to repeatedly expand the head as it is pulled through the pipe. The hydraulic head is used for the most difficult situations, such as cast iron pipe or extremely hard soils.

(4) Replacement pipe can be made of polyethylene (usually high-density), glass fiber, PVC, or stainless steel. When the replacement pipe is made of a plastic, usually the entire replacement length is fused together before the pull begins.

(5) Pipe bursting is the only trenchless technology that allows replacement of an existing, deteriorated pipeline with one of (one or two sizes) larger diameter. However the upper limit for the diameter of replacement pipe is about 30 in. One disadvantage to pipe bursting is that services must be excavated and connected.

(6) The average speed of replacing pipe through pipebursting is about 500 ft/day.

(7) Pipebursting was used at Elmendorf Air Force Base, near Anchorage (*Public Works* 1996]. The base had to replace 4,000 ft of 6-in. cast iron water main along four streets in the housing area. The base also wanted to upsize the main to 8 in. Due to the cold climate of the

region, water lines are buried at least 10 ft underground. This makes open trench replacement impractical, especially in a residential area. The bid for open trench replacement of the water main was $950,000. The cost for using pipebursting technology was less than $600,000.

i. Materials. Three types of materials used in trenchless rehabilitation stand out for their excellent all-around characteristics (Reyna 1994).

(1) Glass-reinforced plastic pipes have a high strength-to-weight ratio and a long design life (over 100 years). They can be used in only slightly curving pipes. Commercially available diameters are 12 to 96 in.

(2) Polyolefin pipes come in a diameter range of 6 to 24 in., have excellent corrosion resistance, and have a design life of 50 years. These pipes can be welded together at the surface in a continuous length before insertion, or they can be threaded together in small sections to allow insertion from smaller access pits. Polyolefin pipes include polyethylene, polypropylene, and polybutylene. Other plastic pipes include PVC and ABS.

(3) Ductile iron pipes are very strong and reliable. They can overcome friction and obstructions more easily than the plastic pipes because they can withstand high stress applied by a ram or winch. However, ductile iron is more susceptible to corrosion than plastic.

j. Cured in Place Pipe (CIPP).

(1) Cured in place pipe (CIPP) is typically a flexible tube constructed of nonwoven polyester felt material impregnated with a resin that hardens after installation.

(2) The entire length of pipe to be installed is delivered to the job site. The lead end of tubing is set into the manhole and anchored into position. Then the rest of the length is inverted (turned inside out) and forced down into the old pipe. Water pressure is produced with a standpipe. The downhole pressure is maintained by continuously adding water to the standpipe to keep a constant head. The water pressure forces the CIPP tightly against the walls of the existing pipe. When the entire length of pipe is inserted, the water inside the CIPP is heated via a heat exchanger in a special boiler truck. This heat touches off an exothermic reaction that changes the resin-coated flexible tube into thermoset plastic. The water is allowed to cool, and is then drained. Workers then cut and seal the ends of the pipe, the laterals, and the manhole connections. Figure 13 shows the process, and Figure 14 shows a cross-section of CIPP.

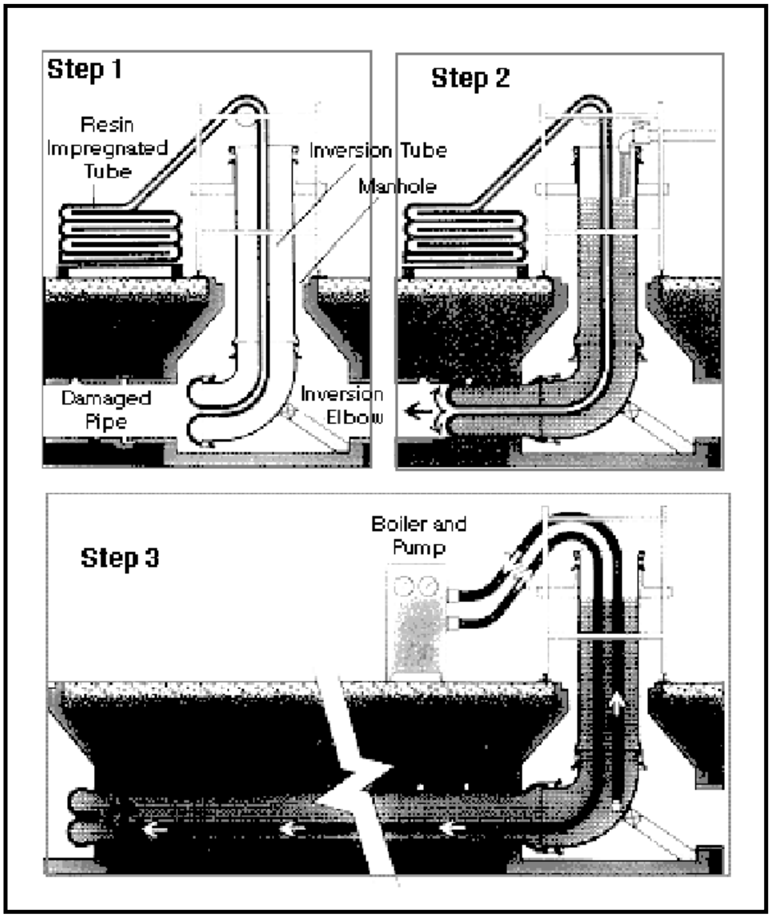

Figure 13. Installation of CIPP (USEPA 1991).

(3) The characteristics of the finished pipe depend on the type of liner used. All types commonly used have excellent resistance to domestic wastewater, and to acids produced by hydrogen sulfide activity. Polyurethane resins are used most often. Vinyl esters and fiberglass epoxies are used in situations calling for extra corrosive resistance or solvent tolerance. Fiberglass epoxy also offers higher adhesion to existing pipe and can withstand high temperatures.

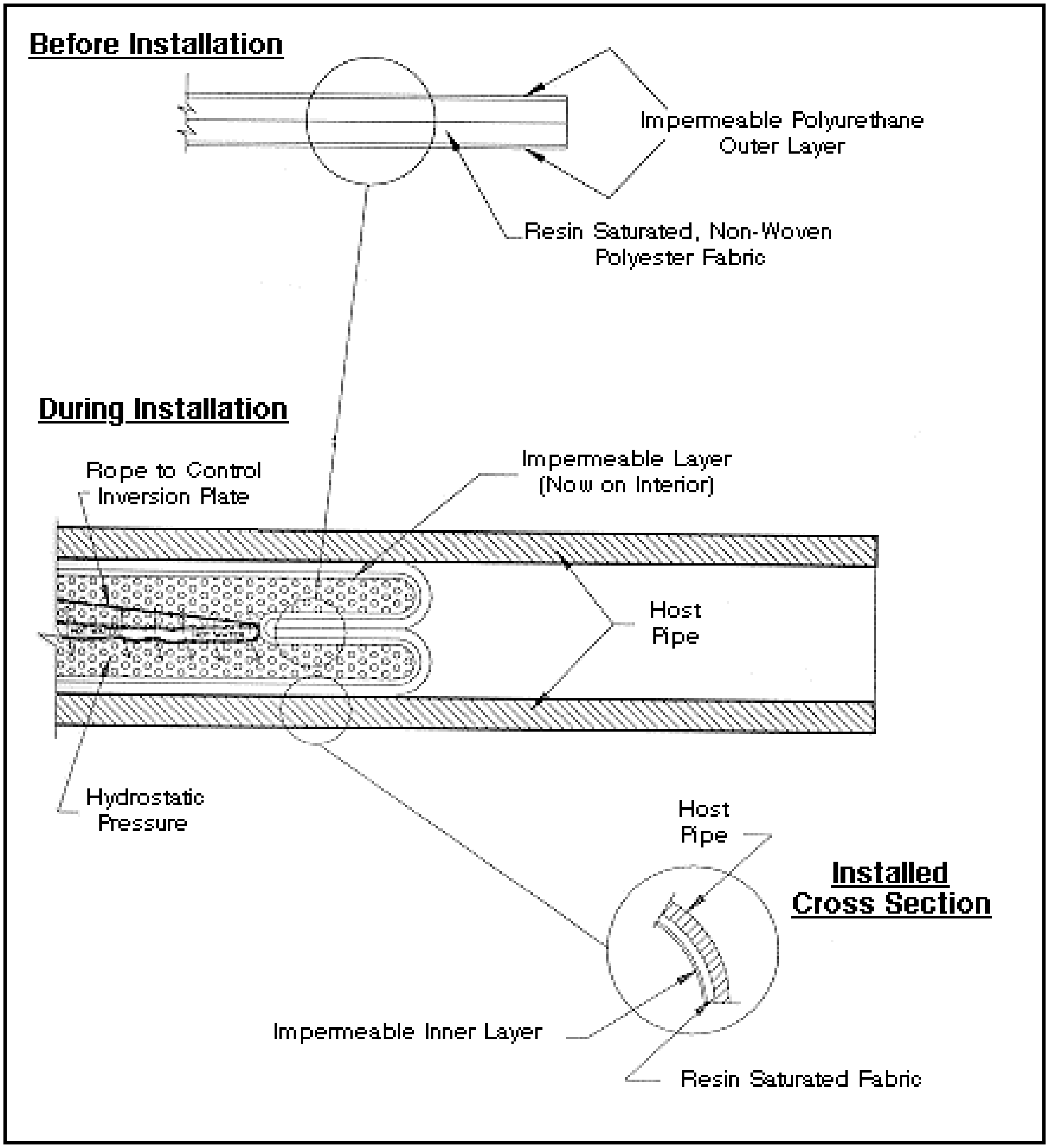

Figure 14. Cross Section of CIPP (Bennett 1995).

(4) One advantage of CIPP is that installation requires no access pits. The insertion/inversion can begin at an existing manhole. It can also be used in pipes with a noncircular cross section. CIPP can also be installed in existing pipe networks with bends, offsets, or misaligned joints.

(5) The CIPP method is most applicable where there is no heavy blockage or extensive structural damage to the existing pipe. The method is commonly used in sewers with diameters between 4 to 24 in., but has been used in some installations of 60-in. diameter. Very long continuous lengths are possible without intermediate access shafts. One sewer remediation in

Boston (Struzziery 1996) installed several continuous CIPP lengths of over 2,000 ft. However the norm is 400 to 600-ft lengths.

k. Folded and Formed Pipe

(1) This group of trenchless methods uses deformed thermoplastics, polyethylene, or polyvinyl chloride to slipline existing pipes. Because the pipe is flexible, access pits are generally not necessary. Existing manhole structures can be used as insertion and exit points.

(2) Two techniques are commercially available: folded pipe and formed (swagged) pipe. Both methods can be used with pipe diameters from 4 to 12 in.

l. Folded Pipe

(1) This method uses a plastic pipe (usually PE) longitudinally folded in upon itself into a "U" shape. The pipe is then wound onto spools and delivered to the jobsite. First, the existing pipe must be carefully cleaned. Then the folded pipe is winched into place. Steam is then introduced into the folded pipe to soften it. Then pressure is applied (25 to 35 psi) to force the folded pipe against the walls of the old pipe.

(2) Drawbacks to this method include the tendency to trap water and debris between the old pipe and the folded pipe as it is forced into place. The system must be allowed time to come into equilibrium after heating and pressure before making lateral connections to ensure that thermal expansion has ceased. Low ground temperatures may make it difficult to apply adequate heat to the system.

(3) A military base in British Columbia used this system to refurbish 2,500 ft of 8-in. concrete sewer pipe (*Water Engineering & Management* 1995). In this typical example, a crew of four completed the job over 10 days, performing nine separate folded pipe insertions. Fold and form pipe generally has a maximum 400-ft length.

(4) A similar folded pipe method uses a folded polyvinyl chloride (PVC) pipe. The first step is to insert a thin-walled plastic "heat containment tube" into the old pipe. Its purpose is to temporarily halt any infiltration, and to serve as a form for the new liner. Then the folded liner, which has been heated for plasticity, is winched through the heat containment tube inside the new pipe. Once the new folded pipe is inserted, a rounding device is pulled through the tube to force open the folded tube, pushing it tightly against the walls of the old pipe. The new pipe hardens as it cools. Finally, branch connections are reopened with a remote control cutting tool in conjunction with remote video inspection.

(5) With this system, the inner diameter of the pipe will decrease by $\frac{1}{2}$ to 1 in. However, the new inner surface will be much smoother, thereby reducing the coefficient of friction and potentially increasing the flow capacity of the line.

m. Swagged Pipe

(1) Swagged pipe, or swagelining, can be used to restore natural gas, water, or sewer lines ranging in diameter from 3 to 24 in. The system starts with a continuous polyethylene pipe

of a slightly larger diameter than the existing pipeline. Under hydraulic pressure, the new pipe is forced through a die which temporarily decreases its diameter (by 7 to 15 percent) such that it will fit into the old pipe. Heat may be applied to soften the pipe.

(2) The new pipe is pulled into place inside the existing pipe with a winch. Load cells monitor the stress on the new pipe. Once the new pipe is fully inserted, it re-expands to form a tight fit with the existing pipe. Additional pressure may be applied inside the new pipe to assure a tight fit to the existing pipe. Service connections can be cut into new pipe via remote control cutters after the pipe is placed.

(3) Swagelining is appropriate only where the existing pipe is relatively structurally intact, thereby allowing the new swagged pipe easy access through the old pipe. Otherwise, an extensive cleanout may be necessary.

n. In-Situ liners. *In-situ* liners refer to a group of trenchless techniques and materials that can be applied to the inside of larger pipes and tunnels. The minimum diameter for these methods is generally considered to be 48 in. This allows easy access by construction workers. These liners are installed to prevent leakage, infiltration, or to provide a corrosion resistant surface. They are commonly used in subway systems. (Large diameter lines are rare in military installations.) These liners require that the original pipe be relatively clean and free of loose and friable debris.

(1) Preformed Strips. Preformed sheets or strips are usually made of a rigid PVC, formed into U-shaped or L-shaped sections. These are attached longitudinally (along the axis) of the pipe under remediation. A temporary scaffold structure is required to hold the strips in place while aligning and fastening them to the original pipe. After all the strips are suspended in place, a cementatious grout is pumped behind them. This grout permanently attaches the strips to the original pipe and to each other, forming a continuous lining.

(2) Geomembrane Sheets. Another method uses HDPE sheets (80 mil thick or greater), preformed into the correct tunnel diameter. They can be completely tubular, or cover only part of the original pipe circumference. The sheets are bolted to the original pipe then welded together to form a continuous liner. There must some kind of venting in this system to relieve pressure build up behind the liner. This may be due to ground water inflow.

(3) Geomembrane Panels. The final *in-situ* type considered here eliminates the inflow pressure problem. Geomembrane panels are fabricated with anchor studs (standoffs) facing outward against the original pipe. The panel is made of HDPE and is usually greater that 120 mil in thickness. The anchor studs extend 0.5 in. or more from the panel (Figure 15). After all the panels are in place, a cementatious grout is pumped in to fill the void space between the panels and the host pipe. This method can be seen as a cross between the previous two: preformed strips and geomembrane sheets.

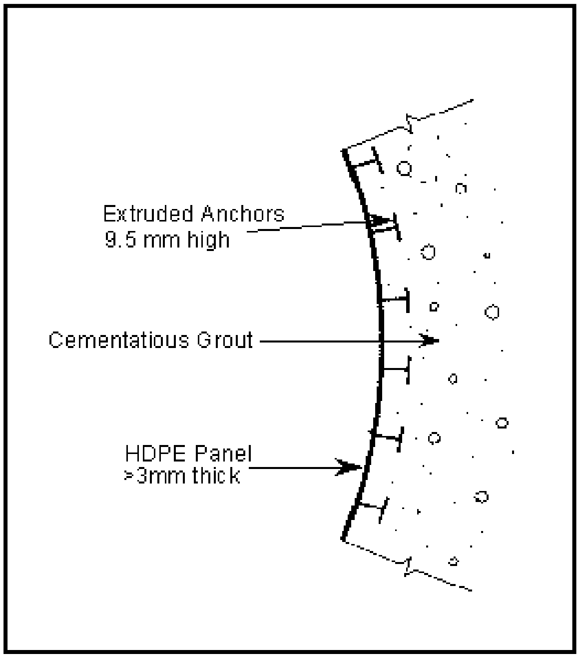

Figure 15. Cross Section Diagram of Geomembrane Panel.

o. Other Materials. Other materials can be applied to the interior of large pipes and tunnels. With any of these materials, the installation process is very labor intensive, largely due to the joining and grouting (Reyna 1994). Some of the properties of other materials applied to the interior of large pipes or tunnels are listed below.

(1) Glass-reinforced cement has a high strength-to-weight ratio and is very resistant to abrasion and chemical attack.

(2) Glass-reinforced plastic is made from fiberglass and either polyester or vinylester. It is also very strong and resistant to abrasion. The interior surface is very smooth, thereby improving flow.

(3) Polyester resin concrete is made up of aggregate and polyester resin. The liner segments formed from this material are very hard, heavy, and brittle. However, the interior of the liner is very smooth, and it is resistant to corrosive chemicals. This material is mostly used in larger sewers.

10. Comparisons. Comparisons between trenchless technologies are difficult because they are relatively new, and because different contractors or agencies may use different nomenclature. the following paragraphs include rough rules of thumb for comparing the cost of some trenchless technologies.

a. Rehabilitation Methods. When choosing a method for new pipeline construction, the most important criteria to consider are (Derr 1994):

- Surface conditions (e.g., safety considerations, traffic, or structures that could interfere with access, etc.).

- Cost.

- Subsurface conditions (e.g., soil type, depth).

- Current condition of piping (e.g., breakage, offsets, branches, etc.).

- Capacity.

(1) The engineer must consider the current flow in the pipe network and ultimate capacity. This will help determine if the pipes must be replaced with ones of smaller, same, or larger diameters. Any of these conditions may be met with open trench construction.

(2) For trenchless methods, pipebursting is required to upsize pipe diameter. To rehabilitate to the same size, pipebursting, folded and formed pipe, or CIPP would work. Recall that in these last two methods, the installed liner does not decrease the pipe diameter very much and the smooth liner surface improves flow. To decrease the installed pipe diameter, any of the trenchless methods may be used, as can any open-trench method Table 2 lists characteristics of several types of pipe remediation for comparison. Table 3 lists characteristics of trenchless methods.

Table 2

Comparison of Five Types of Pipe Remediation (Koerner 1996)

Method	Typical Diameter (in)	Advantages	Disadvantages
Coatings	>48	Inexpensive Conforms to host pipe No access pits No volume reduction	Clean, dry surface required Limited lifetime Frequent maintenance May sag
Slip Linings	4-36	Creates new structure No surface prep needed Can expand size with pipebursting No bypass required	Expensive Curves and bends difficult Requires large access pits Flow reduction
Cured-in-place-pipe	4-24	Conforms to existing pipe No access pits Small volume reduction No joints	Expensive Some surface prep Specialized equipment Complex chemical system
Folded and Formed Pipe	4-12	Conforms to host pipe No access pits Small volume reduction No joints	Expensive Careful surface prep Specialized equipment
In-situ liners	>48	conforms to host pipe Slight volume reduction	Expensive Some surface prep May require access pits Need secure anchoring

Table 3

Trenchless Methods Compared

Method	Bypass Pump	Excavate Services	Clean Line First	Upsize
CIPP	Yes	No	Yes	No
Burst	Yes	Yes	No	Yes
Crush	Yes	Yes	No	Yes
Slipline	No	Yes	Yes	No
Spiral Wound	Yes	Yes	Yes	No
Fold and Form	Yes	No	Yes	No
Swageliner	Yes	Yes	Yes	No
Grouting	No	N/A	Yes	N/A
Excavate	Yes	Yes	No	Yes

b. Available Cost Comparisons

(1) Many indirect costs are associated with open trench construction. Table 4 lists direct costs associated with open trench pipe replacement. Whoever performs cost comparisons between trench and trenchless methods for the same job must remember to include indirect costs. Open trench construction can result in large quantities of excavated soil and muck, for which there may be a disposal cost, especially if there is any contamination. There are indirect social costs as well with open trench methods, ranging from unhappy residents to reduction in productive activity.

(2) Microtunneling, and the other trenchless construction methods, are generally more cost effective with deep installations and in locations with high water tables. This is because the cost of open trench technology is proportional to the depth required and the amount of groundwater that must be continually pumped out of the trench. Table 5 lists approximate costs associated with five pipe rehabilitation methods, and Table 6 lists approximate costs associated with rehabilitation technologies.

Table 4

Cost of Open Trench Pipe Replacement [USEPA 1991]

Pipe Diameter (in)	Replacement cost ($/linear foot)*
12	80
14	90
16	95
18	110
20	125
30	180
40	245
48	290
54	320
60	365
72	460
90	590
102	690
*Values are updated using the Engineering News Record Cost Construction Index are for quick reference only. There has been extensive competition in the trenchless technology area and costs may reflect that competition.	

Table 5

Cost Comparison of Five Pipe
Rehabilitation Methods [Koerner 1996]

Method	**Approximate Cost* ($/sq ft)****
Coatings	10-20
Slip Linings	30-50
Cured-in-place-pipe	30-40
Folded and Formed Pipe	25-35
in-situ liners	20-30

*Values are updated using the Engineering News Record Cost Construction Index are for quick reference only. There has been extensive competition in the trenchless technology area and costs may reflect that competition.

** The square feet of internal pipe surface can be calculated by the formula: ID * A * LF, where ID is the internal pipe diameter (ft), A is 3.14159, and LF is linear feet of pipe.

Table 6

Cost Comparisons of Rehabilitation Technologies,
Per Linear Foot Installed (USEPA 1991)

Pipe Diameter (in)	Grouting ($/lf)*	Sliplining Polyethylene ($/lf)	Cured in place pipe ($/lf)	Cement mortar coating ($/lf)	Shotcrete coating ($/lf)
6	30	60	48		
8	35	60			
10	45	70	83		
12	50	75		25	
14	55	85	115		
16		100			
18	60	90	145		
22	100	110	155	28	
26		135	195		
28	130	160			
32		180	230		
36	180	215	255	35	
42		255	280		
48		300	330	45	160
52		330	370		190
58		390	380	50	210
68		445			220
72		500			260
80		590			290
88		650			
92		730			330
100		800			370

*Values are updated using the Engineering News Record Cost Construction Index are for quick reference only. There has been extensive competition in the trenchless technology area and costs may reflect that competition.

APPENDIX A

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APPENDIX B

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