Underground Cable Installation and System Cost Reduction

Phase 2: Design Tradeoffs

TR-114457

Final Report, December 1999

EPRI Project Manager
T.J. Rodenbaugh

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Power Delivery Consultants, Inc.
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CITATIONS

This report was prepared by

Power Delivery Consultants, Inc.
28 Lundy Lane
Ballston Lake, New York 12019-2107

Principal Investigator
J. Williams

Sargent and Lundy, LLC
55 East Monroe Street
Chicago, Illinois 60603

Principal Investigator
J. Conidi

Power Cable Consultants
220 Sweetman Road
Ballston Spa, New York 12020

Principal Investigator
T. Aabo

InfraCorps International
20027 120th, Avenue SE
Kent, Washington 98031

Principal Investigator
M.J. Kirby

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REPORT SUMMARY

Lowering the costs of designing and installing underground transmission systems would make such systems more attractive alternatives to overhead transmission lines. The first phase of this project examined typical utility practices for installing underground transmission line systems. This final phase examined alternative methods for the design and installation of underground cable systems, particularly 115-kV and 138-kV cross-linked polyethylene (XLPE) cable installations. This phase of the work addressed a number of technical issues associated with cable installation, including circuit rating, trench configuration, and trench construction. Cost-saving installation approaches evaluated ranged from pipe lining technologies to fast microtunneling and plowing-in cables.

Background

Although underground transmission systems can be more costly to install and maintain than overhead transmission circuits, they offer promising alternatives to the growing costs and difficulties encountered with new construction of overhead transmission lines. Increasingly, underground cables may be the only alternative, as obtaining rights-of-way for new overhead lines is becoming prohibitively more expensive and time-consuming in many areas. EPRI sponsored this investigation of alternative design and installation approaches to help lower the cost of future underground transmission system installations.

Objective

To evaluate alternative low-cost methods for the design and installation of underground cables.

Approach

Based on the findings of the Phase 1 project, the project team investigated areas that appeared most likely to result in cost savings on the installation of underground cable systems. These investigations focused on methods that affect installations of 115-kV and 138-kV systems utilizing XLPE cables. Technical issues addressed included circuit rating, trench configuration, and trench construction.

Results

The results of these investigations indicated that several alternative technologies and design approaches can reduce the overall cost of underground cable systems. These alternative approaches include pipe lining technologies, design standardization, auger boring, fast microtunneling and plowing-in cables. Plowing-in or installing extruded dielectric cables in slit trenches, for example, can reduce civil works costs by as much as one-third, with little effect on the electrical capability of the cable circuit (ampacity). Since civil costs typically account for

more than half of the total installed cost for a cable system, plowing or slit trenches offer significant advantages where their use is feasible.

EPRI Perspective

An exhaustive study of cable design versus construction design would be an overwhelming effort. Initially this project was designed to achieve just that. After identifying various designs, it became evident that there could be hundreds of interactions and factors affecting ampacity. The research team also considered tradeoffs and their associated business risks. This too became an overwhelming proposition. As a result EPRI decided to limit the analyses to the installation approaches included in this report. Should there be a future interest in this subject, EPRI suggests that the list of design tradeoffs be revisited. This report covers many ideas that offer significant cost benefits and represents a follow-on to EPRI's Underground Cable Installation and System Cost Reduction, Phase 1 report (TR-109150).

TR-114457

Keywords

Underground transmission
Costs
Construction costs
Power transmission planning

ABSTRACT

This report summarizes the results of the investigations that were conducted to explore methodologies could be used to lower the cost of underground transmission lines. The investigations centered on installations of 115 kV and 138 kV XLPE cable installations. The objective of the study was to identify lower cost alternatives to present practices. A number of technical issues were addressed in the study, including circuit rating; trench configuration; trench construction; and cable installation.

The search for best practices and the application of these practices can lower the cost of underground transmission lines leading to a greater number of installations. The implementation of the cable system engineering and installation methods described in this report can lead to reduced overall costs.

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PLOWING-IN TRANSMISSION CABLES AND USING NARROW, SHALLOW TRENCHES

Introduction

Plowing-in transmission cables, or installing them in slit trenches, offers significant savings in civil costs in areas where conditions permit. Plowing-in was not a feasible approach for pipe-type cables because of the large, rigid steel pipes and the need to make pipe joints every forty feet. However, as extruded-dielectric cables become much more common, the advantages of plowing-in these cable types or installing them in slit trenches – either directly or in duct – appears feasible and can provide significant benefit in terms of both cost and installation time. A 1995 article[1] describes a 23-kV installation on Long Island.

Applicable Routes

Plowing-in at traditional depths appears to be feasible only in rural areas, or suburban areas that do not have existing services such as telephone, water, power, etc. Installations along railroads and petroleum pipeline rights-of-way could be ideal. In urban and built-up suburban areas, the cost of cutting and restoring existing services, and the disruption to customers, may offset any cost savings of plowing-in. However, in these cases installation at shallow depths may be feasible.

Installation along a utility right-of-way used for overhead lines appears ideal for plowing-in transmission cables, in terms of equipment access, gentle bends, and lack of other underground services. Rough terrain can present problems, however, so any potential route should be carefully reviewed.

Plowing-in will be more difficult in rocky areas or other locations where the plow assembly is unable to move through the soil. Pre-plowing to identify obstacles has been used; the obstacle such as a boulder can be removed before cable plowing begins.

Slit trenches appear feasible in all installation areas. Rock cutters may be especially attractive as a way to open the trench in rocky areas.

[1] Mailman, Mitchell "Plowing-in Underground Cable," *Transmission and Distribution*, August, 1995. Pgs 20-23.

Installation Issues

Trench Configuration

We evaluated a conventional ductbank installation as a base case, versus a narrow trench configuration that could be accomplished either by plowing, or by using a ladder trencher or other method to create a slit trench.

Figure 1-1 shows the traditional trench design used as our base case.

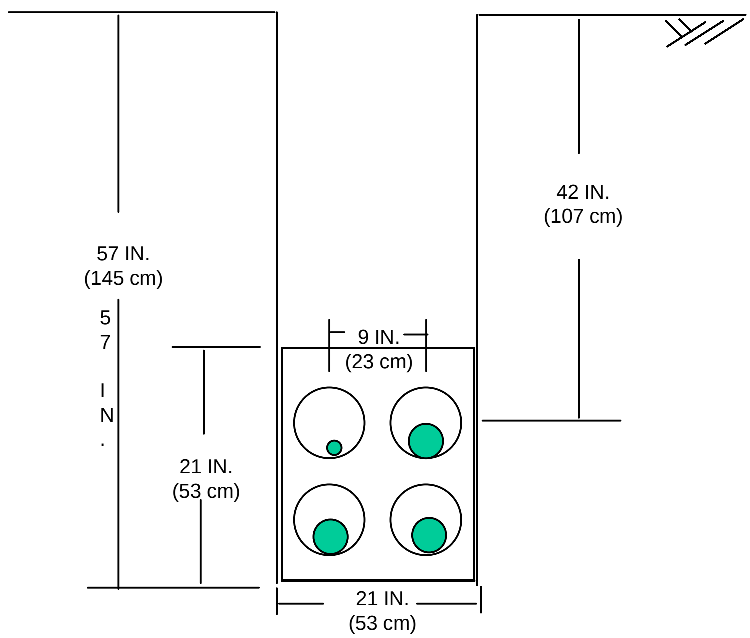


Figure 1-1
Conventional Trench

Figure 1-2 shows the slit trench, for vertical and trefoil cable configuration. The cables in this trench may be installed directly buried, or in conduit. It is possible to “extrude” concrete around the cable or duct as the cable/duct is being installed, or to pour concrete into the trench.

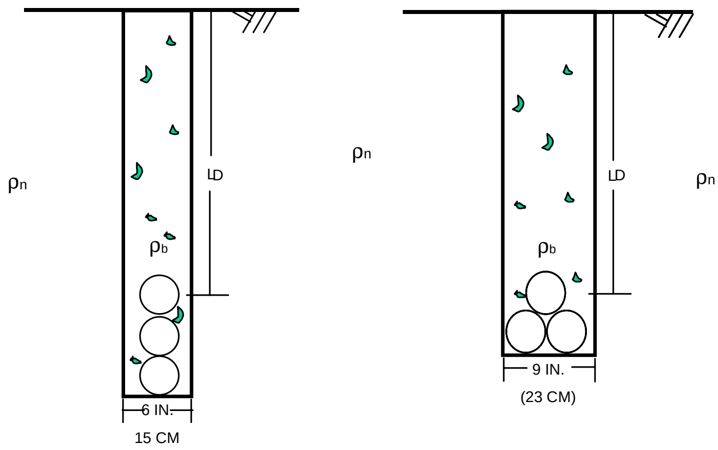


Figure 1-2
Slit trenches. 1.2a Random installation; 1.2b Trefoil installation

Conventional depth is approximately 42 inches; shallow depth is approximately 13.5 inches.

Several issues are addressed for plowing-in and slit trenches.

- Protection for shallow burial
- Ampacity effects
- Crossing other utilities
- Cable installation equipment
- Cable access for repair
- Joint locations

Equipment Issues

Plowing-in plastic water pipes for irrigation is fairly common in parts of the country. That equipment should form a good starting point for plowing-in ducts, and perhaps for plowing-in cables directly. Narrow slit trenches are becoming more common for suburban and urban installations of fiber optic cables and CATV cables. The width, often six inches (15 cm), is sufficient for installing one cable at a time, but is too narrow for the installation of three 138-kV power cables in the trefoil configuration. Extending from six inches to nine inches (23 cm) or so should not be a major step.

Several contractors in this country have developed equipment for paying-off transmission cables into trenches. Most of this equipment is directed toward one phase at a time; equipment would have to be developed to install all three phase at once, which is necessary to reduce costs to the minimum feasible level. Three reels each containing 2000 feet (610 m) of a large copper-conductor XLPE cable would be very heavy; a substantial piece of equipment would be required.

Three passes, each installing a single phase cable, is an alternate that will be only slightly more costly. Three passes in a slit trench should be straightforward. For plowing, the three phases would have to be separated by several feet to avoid potential damage. This would be more costly than a single pass, would widen the right-of-way, and would increase standing voltages, but would increase ampacity.

Equipment exists to "extrude" a concrete layer around a plowed-in plastic pipe up to several inches diameter. Equipment development will be needed to extend the equipment to a larger pipe size. As discussed in this chapter, this concrete extrusion will not have a major effect on ampacity, but it may be necessary to provide mechanical protection against dig-in or damage from rocky soils.

In summary, equipment exists for installation of at least the smallest cable sizes. That equipment will have to be extended to handle larger sizes, and to handle the most cost-effective installation – three cables installed at one time.

Cable-Construction Requirements

In conventional cable installations, the installer removes rocks and other sharp objects from the trench to avoid potential cable damage. One disadvantage of plowing-in cables or using slit trenches is that the installer will not be able to remove – or even observe – objects that may damage the cable.

One solution is to install the cable in ducts, similar to the Cable-In-Conduit (CIC) system used for distribution cables. For options where a single cable is installed per duct, the cable could be pre-installed in the duct or the duct could be installed in the plowing operation, and the cable pulled at a later time. Three cables in a single duct, as in Figure 1-2b, is probably not feasible since it is unlikely that the required 8 – 10 inch (20 – 25 mc) diameter duct could be provided on a reel – "sticks" of duct would be needed. Duct installation has the disadvantages of higher cost and lower ampacity.

The construction of a typical extruded-dielectric transmission cable is quite rugged: an 0.125-inch (3 mm) high-density polyethylene jacket is placed over the cable shield/sheath – and special abrasion-resistant jackets can be obtained. The jacket – perhaps reinforced or with additional thickness – may be able to provide adequate mechanical protection in most soils. This is an area to be investigated if plowing-in or slit trenching is selected as a method to investigate further.

Ampacity

Plowing-in does not provide much opportunity to install high-quality controlled backfill or duct envelope, as can be done in a conventional trench. However, it is possible to "extrude" a several-inch concrete envelope around the cable or duct to provide mechanical protection and improve ampacity.

We calculated ampacities for different installation conditions, for a 750-kcmil (380 mm^2) aluminum conductor, and a 1500 kcmil (760 mm^2) copper conductor cable. Basic ampacity parameters are given in Table 1-1. We calculated all ampacities for a single circuit. Plowing or slit trenching has the advantage that two circuits can be placed 12 or more feet (4 or more meters) apart so that they are thermally remote.

Table 1-1
Basic Parameters for Ampacity Analysis

Parameter	**Value**
Voltage	138 kV
Insulation thickness	0.700 inch (17.8 mm)
Outer shielding	Aluminum foil cigarette wrap plus drain wires
Load factor	0.75 per unit
Ambient earth temperature	32°C at 12-inch (30.5 cm) depth 27°C at 42 inch (107 cm) depth
Soil thermal resistivity	90C°-cm/watt
Bonding	Multi-point, plus cross-bonding

We calculated the following ampacities for conventional 42-inch (107 cm) burial depth:

Table 1-2
Calculated Ampacities, Amperes Conventional Burial Depth

System	750 kcmil (380 mm^2) Al		1500 kcmil (760 mm^2) Cu	
	Multi-Point Bonded	Cross Bonded	Multi-Point Bonded	Cross Bonded
Conventional, Figure 1-1	502	609	723	1163
Slit Trench, Figure 1-2a				
No Envelope, Direct Buried	591	603	962	1035*
No Envelope, Duct	521	584	772	1082*
3-inch Envelope, Direct Buried	611	623	998	1072*
3-inch Envelope, Duct	529	592	786	1099*
Slit Trench, Figure 1-2b				
No Envelope, Direct Buried	592	611	920	1097
No Envelope, Duct	510	590	739	1110
3-inch Envelope, Direct Buried	613	633	959	1139
3-inch Envelope, Duct	520	600	757	1132

** The duct-installed cable has a higher ampacity because the increased spacing vs. directly-buried cable gives a lower sheath loss which offsets the higher thermal resistance of the cable in the duct.*

Several comments can be made on these ampacities:

- Direct burial provides substantial ampacity increases, as is expected.
- Placing a three-inch low thermal resistivity concrete envelope around the cable provides a 5% or lower ampacity increase, which is not a significant improvement considering the cost of adding the concrete. (Note, however, that plowing-in cables, especially with a vibratory plow, can create air pockets that will have high thermal resistivity. The concrete would fill those air voids.
- The wider trench with trefoil configuration has a slightly better ampacity – but only by a few percent.

Ampacities were also calculated for a shallow burial depth of twelve inches (30.5 cm) to the top of the cable or duct. Results are summarized in Table 1-3.

Table 1-3
Calculated Ampacities, Amperes Shallow Burial Depth

System	750 kcmil (380 mm^2) Al		1500 kcmil (760 mm^2) Cu	
	Multi-Point Bonded	Cross Bonded	Multi-Point Bonded	Cross Bonded
Conventional, Figure 1-1	502	609	723	1163
Slit Trench, Figure 1-2a				
No Envelope, Direct Buried	628	640	1048	1121
No Envelope, Duct	543	604	821	1133
3-inch Envelope, Direct Buried	655	667	1101	1175
3-inch Envelope, Duct	552	614	840	1155
Slit Trench, Figure 1-2b				
No Envelope, Direct Buried	636	655	1023	1202
No Envelope, Duct	543	620	807	1184
3-inch Envelope, Direct Buried	666	685	1085	1265
3-inch Envelope, Duct	557	634	835	1216

The ampacity increase for shallow burial averages 7.5%. One might expect a greater increase because of the much shorter heat flow path from cable to earth surface. However, there are two offsetting factors: the ambient earth temperature is higher at the shallower depths, and the heat absorption – especially if the cables are under asphalt – has a larger effect. The above calculations do not take into account the possibility of a non-isothermal earth surface or the earth-to-air surface thermal resistance, both of which will reduce ampacity somewhat.

Long-term emergency ampacities – typically 24 hours and longer – will not be as great for the shallow-depth cable, since the effective thermal mass of the earth is reduced.

Installation and Operation Issues

Protection for Shallow Burial

Extruded-dielectric transmission cables have excellent reliability, and it should be feasible to place structural strength concrete immediately around the cables to provide mechanical protection. The chances of failure in the cable section are very small. If failure did occur, the utility would have to expose the concrete, break it away from the cable, repair the cable, and replace concrete. With proper care, this can be done without damaging the cable.

Potential users of the slit trench or plowing-in will have to address the concern that a backhoe bucket will grab the cables from the side – having concrete fill the trench above the cables will provide little protection. Making the trench wider to allow three inches (7.5 cm) of concrete on either side of the cables will provide almost the same protection as a conventional ductbank. If cutback is needed for paving, placing a steel or cast concrete plate over the trench will provide additional protection.

If cable is directly buried and difficult to access, the utility would have to be sure to properly size the cable shield/sheath to insure that fault currents do not damage large sections of cable.

Placing the cable in individual ducts, or a single larger duct, will eliminate the concern about having to remove concrete in event of cable failure.

(Note that, at a cable price of $30 per foot,($98 per meter) replacing a 2000-foot (610 meter) manhole-to-manhole section and remaking two splices will cost about $100,000. It would generally be less costly to place a splice – or even a short "dutchman" and two splices – at the failure location. This will be especially true in the case where the three cables are installed in a common duct.)

Splice Locations; Standing Voltages

For the plowing-in or slit trenches to be cost effective, long cable sections need to be installed. We have assumed 2000-foot sections, although longer sections should be feasible. At splice locations, excavation will be required to provide a splice pit or manhole of conventional dimensions. Although this will add cost, the infrequency of the splice locations should mean that the effect on overall project cost will be small.

Even if the circuit carries 1000 amperes, standing voltage will be less than 100 volts, which is a value, accepted by many utilities.

Crossing other U1tilities

If a shallow trench is permitted, crossing over other utilities should present no problems. However, the need to cross under other utilities may defeat the potential economies of plowing and slit trenches. Some contractors say it is cheaper to simply sever the services (with appropriate warnings to affected parties) and restore them – except for gas lines and telecommunications. This will be difficult for the plowed/slit trench installation, however, since the intent is to have the trench so narrow that a man cannot enter.

Therefore, plowing or slit trenching is not considered an option where other utilities must be crossed – unless the cable crossing is above the other services.

Cost Implications

The slit trench installation of Figure 1-1 or 1-2b has significant cost savings compared to a conventional installation as shown in Figure 1-1. Calculating all costs for each of the installation conditions given in Table 1-4 is too unwieldy. We therefore calculated costs for one cable: the 750-kcmil (380 mm^2) aluminum-conductor, cross-bonded system. Conventional and shallow depths were analyzed.

We calculated costs for civil works, cable, and cable installation. Results are shown in Table 8-2. For the directly-buried systems not having a concrete envelope, we added 5% to the cable cost to provide for a more rugged jacket. Costs are for a line assumed to be 10,000 feet (3050 meters) long. Prices are on a per-unit basis, and do not include many costs such as link boxes, terminations, terminal structures, overheads, etc. Note that the different trench configurations have different ampacities. Rather than normalizing the costs based upon ampacity, we have noted the ampacity for each installation mode. Ampacities are for 750 kcmil (380 mm^2) aluminum conductor cable, cross-bonded.

Table 1-4
Relative Costs, Different Trench Configurations

System	Civil Works
Conventional, Figure 1-1 (609 A)	1.0
Slit Trench, Figure 1-2a	
No envelope, direct buried (640 A)	0.68
No envelope, duct (604 A)	0.90
Concrete envelope, buried (667 A)	0.72
Concrete envelope, duct (614 A)	0.92
Slit Trench, Figure 1-2b	
No envelope, direct buried (655 A)	0.79
No envelope, duct (520 A)	0.95
Concrete envelope, buried (685 A)	0.66
Concrete envelope, duct (634 A)	0.96

Cost Implications — Summary

Plowing and slit trenches can reduce civil works costs by as much as one-third, with little effect on ampacity. Since civil costs typically account for more than half of the total installed cost for a cable system, plowing or slit trenches offer significant advantages where their use is feasible.

Further Investigation

The approaches in this section appear technically feasible and are certainly effective in reducing the cable system cost. Steps suggested to demonstrate the concept are summarized as follows:

Investigate specific equipment suppliers and installation contractors to verify suitability of the approaches.

If duct is not to be used, discuss "super-tough" jackets with cable suppliers.

Solicit several potential host utilities and meet to discuss potential safety and reliability concerns. Perhaps obtain an interpretation of the National Electric Safety Code.

Once a utility has agreed to host the demonstration, design a cable system to meet load requirements. Specify cable and installation methods, and work closely with the utility, the civil contractor, and the cable installation contractor, to perform the installation. Include temperature monitoring to verify the accuracy of ampacity calculations.

2
PIPE LINING TECHNOLOGY

Introduction

Pipe lining technology has evolved as one of the premier trenchless technologies for refurbishing and repairing leaking water, wastewater and gas pipes. Trenchless technology is the installation, repair, refurbishment or replacement of underground utilities and infrastructure without the disruption and expense of open trenching.

Several pipe lining technologies were investigated for their potential application to fast and economical open trenching for electric transmission casing installation. These pipe- lining technologies were investigated for their potential to speed or streamline open trenching operations. Open trenching for electric transmission installation involves using 20-ft to 40-ft sections of polyvinyl chloride (PVC) pipe that must be glued together and placed into a trench before backfilling and compacting. The gluing process is time consuming and seems to be a pacing element in the trenching process. Continuous polyethylene (PE) pipe can be used as an alternate to PVC because it is available on large diameter reels. PE pipe is only available in 6-inch and smaller diameters on reels. The larger sizes required for electric transmission installations are not available due to reel size constraints. These reels contain approximately 500-ft and make installation quicker than gluing PVC.

Other recently developed trenchless technologies may hold potential for lower cost transmission installation. The pipe lining technologies that appeared to have the greatest potential for fast and low cost installation are as follows:

- Fold and Form Pipe
- Cured in Place Pipe (CIPP)
- Spiral Wound Pipe

Fold and Form Pipe

Description

The PVC or PE pipe is usually folded and formed for installation in existing steel, cast iron, clay or concrete pipe that is damaged and leaking. The pipe is folded to allow it to be easily pulled into the existing host pipe. The pipe with a thin (SDR 32.5) wall is heated and folded into a shape similar to that shown in Figure 2-1. The pipe will retain this shape until heat is again applied to allow it to form into a new shape inside the pipe. The folded and collapsed shape provides for clearance for the pipe to be easily pulled into the old pipe and allows for much more pipe to be stored on a reel. This pipe is available for lining 6-inch (152.4 mm) to 36-inch (914.4 mm) diameter pipe.

Process Steps

Fold and form process usually begins with high-pressure water-jet cleaning of the pipe to ensure that all roots and pipe occlusions are cleaned from the interior wall. Once cleaned and inspected the fold and form pipe is cut to a length slightly longer than the hose pipe and pulled into place. Connections are made to each end of the fold and form pipe to allow the low-pressure steam or water to be pumped through the pipe. The PVC or PE pipe is filled with steam at approximately 150-190 degrees F (340-360 degrees k) at 5 to 15 psi (34.5 to 103.5 kpa). The temperature softens the material and allows the pipe to deform and conform to the wall of the host pipe. This temperature is applied to the pipe for a period of two to four hours. After cooling the pipe conforms permanently to the inside of the host pipe. Once in place the ends are terminated and lateral connections are made.

Advantages

The principle advantages of the fold and form pipe is that it is quick and easy to install. It is durable and can conform easily to the inside of the host pipe. It is a relatively clean operation that requires only steam and or water to cure. It is inexpensive when compared with open-trench pipe replacement. Fold and form pipe is available in PE or PVC material, is water tight and resistant to most common chemicals.

Figure 2-1
Fold and Form Pipe

Cost

The cost for fold and form pipe is approximately as follows:

6-inch diameter (152.4 mm) $32 – 35/ft installed ($105-$115/m)

10-inch diameter (254 mm) $40 - $45/ft installed ($130-$150/m)

Electric Transmission Application

In order to use this technology for electric transmission application the pipe would be laid in a narrow open trench and steam or water would be applied. Care must be taken to ensure that the pipe does not balloon at any one section. The material can be very soft when heated. A hose can be used inside the PE of PVC pipe to restrain the amount of movement allowed when heated. Fast setting neat cement can be poured over the pipe as it is curing. Care must be taken to ensure that the pressure of the cement grout does not cause the remainder of the pipe to "balloon" when the cement is poured. Use of an internal hose to support the pipe would eliminate this risk but add to the complexity of the operation. Fast setting cement creates excess heat from the exothermic chemical reaction in the cement. This additional heat can help set the PE or PVC pipe.

Manufacturers and Suppliers

There are currently seven (7) companies supplying various forms of fold and form pipe. The companies are as follows:

- AM-Line (PVC)
- CSR Pipeline Systems (PE)
- EXmethod (PVC)
- NuPipe (PVC)
- Sure-Line (PE)
- U-Liner (PE)
- Ultraliner (PVC Alloy)

Cured In Place Pipe (CIPP)

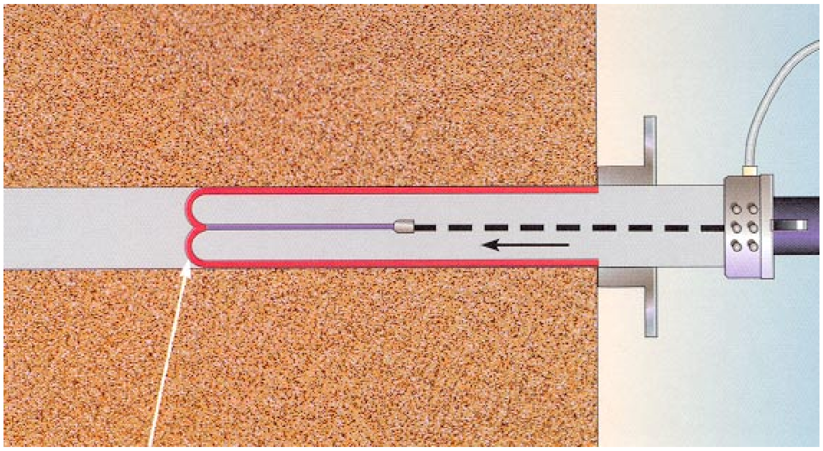
Description

CIPP technology is designed as a pipe lining system to repair and refurbish leaking water, wastewater and gas pipe. The process involves inserting an epoxy impregnated sock into a pipe and inflating it with hot water or steam to conform to the inside of the pipe. Heat is required to cure the epoxy. The heat-cured epoxy liner seals the pipe, provides minimal additional structural strength and provides a slightly smoother surface to reduce flow losses. This process has been successful for many years in the water and wastewater industry and recently has been applied to the gas industry. These systems have been used to line pipes from ¾-inch (19.1 mm) to several meters in diameter.

Figure 2-2
Cured in Place Pipe (CIPP)

Process Steps

The host pipe, to be sealed, must be cleaned with high-pressure jets and inspected prior to installation. The fiberglass sock is impregnated with epoxy and kept refrigerated before installation to prevent curing before placement. The sock is pulled into the host pipe snuggly and sealed off on each end so that excess material cannot wrinkle once the sock is expanded. Some installations are done in an inversion process using low-pressure air or water as shown in the figure. The sock is filled with hot water and expanded to fit the host pipe. The curing process is a two-stage process with the initial stage cured at 140 degrees F (330 degrees k) for 2 - 4 hours and the second stage at 190 degrees F (360 degrees k) for 2 - 4 hours. Curing times and temperatures vary depending upon the thickness of the material and other environmental conditions. One manufacturer cures the epoxy with ultraviolet (UV) light.



Inversion Lining Process

Figure 2-3
CIPP Installations in an Inversion Process

Advantages

The advantages of the CIPP process is that it creates a thin seal in the host pipe. It is very compliant, more so than the PVC or PE pipe systems. It seals the host pipe with less wall thickness compared with thicker PVC or PE pipes. The thin wall provides a larger internal diameter and more flow capacity than fold and form pipe. It does require more labor, is more expensive and a bit messier than the fold and form liners. It is water tight and resistant to most chemicals.

Price

This technology is priced, like the others, as “installed” in the host pipe. This generally includes cleaning and preparation of the pipe and cutting all holes for sewer laterals as well as inspection to ensure that installation has been properly carried out. The price is $30-$42/ft $100-$140/m) for a 6-inch (152.4 mm) diameter pipe and $50-$70/ft ($165-$230/m) for a 10 inch (254 mm) diameter pipe.

Transmission Application

The CIPP technology must be used with a internal hose to inflate the epoxy impregnated sock. Several suppliers provide a sock which is impermeable, in the wet stage, but most are not. If pressurized without a containment host pipe they will leak and allow water or steam to pass through the porous material. This technology would work best in an open trench application by placing a hose inside the sock and using the hose to resist the weight of the cement grout that would be poured onto it. The heat of the fast setting cement grout will help cure the epoxy. Once the epoxy and cement have reached sufficient cure strength the hose could be removed. Tests would have to be performed to determine the proper cure time to reach adequate strength for removal of the internal hose.

Manufacturers and Suppliers

- Amex Line
- CIPP Liner
- Cure-Line
- InLiner Advantage
- Impreline
- Inpipe (Sweden)
- Insituform
- ITG Liner
- Masterliner
- Multiliner
- National Liner
- Paltem
- Performance Liner
- Phoenix
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Spiral Wound Pipe

Description

This pipe is available in steel, PVC and PE construction and a combination of steel and PE or PVC. The combination pipe uses PE of PVC as the seal for the locking section. This pipe is available from 6-inch (152.4 mm) diameter to 48-inch (1.2192 m) diameter. The pipe comes on reels as flat material and is wound into a pipe in a spiral wrap as the edges are connected in a continuous “push-lock” fashion designed into the pipe edge to make a water tight pipe. The finished pipe is generally grouted to the host pipe to seal the interface between the host and the new pipe to increase the structural strength of the combined pipe. A winding machine is generally used to join the pipe edge.

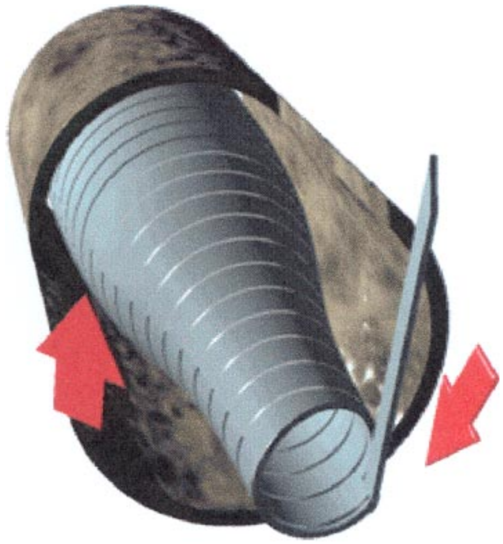


Figure 2-4
Spiral Wound Pipe

Process Steps

The host pipe is cleaned and inspected to ensure there are not obstructions, roots or collapsed sections. The winding machine is installed in the entrance pit and the flat material is fed from a reel into the machine, the edges are clipped together at the seal. The joint is sealed as the edges are clipped together. When the spiral pipe reaches the opposite end of the host pipe the end is restrained from rotating and the diameter expands as the joints slip until the spiral pipe reaches the diameter of the host pipe. This process continues until the spiral pipe has expanded over its complete length. The pipe ends are cut flush with the manhole and grouted to seal them from water intrusion.

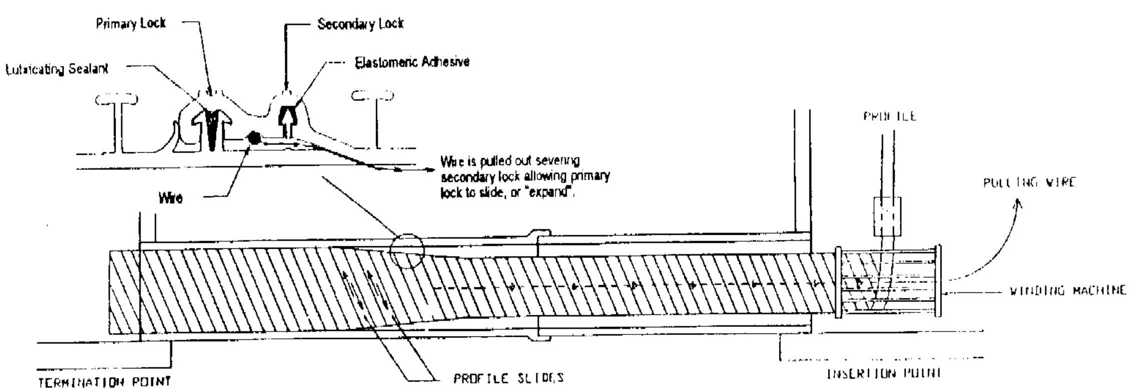


Figure 2-5
Spiral Wound Pipe Installation Process

Advantages

The advantage of spiral wound pipe is that there is no heat curing process required. The pipe is inexpensive and has excellent structural integrity. It is water and chemical resistant and can be manufactured in nearly all common materials. The installation process is quick and adapts to a wide range of host pipe sizes. The pipe and process are clean and require little auxiliary equipment.

Price

The price of this pipe lining system is approximately $30/ft ($100/m) for a 6-inch (152.4 mm) diameter installation to $50/ft ($165/m) for a 10-inch (254 mm) diameter installation. This price includes all pipe cleaning, inspection and grouting.

Transmission Application

This technology is perhaps the easiest to adapt to transmission pipe installations. The pipe would be rolled together in a continuous process off the back of truck and fed into an open trench. Since no thermal cure is required, cement grout can be poured immediately on the formed pipe. The pipe would be formed in the final diameter thereby eliminating the resizing process where one end is restrained to allow the pipe to expand. The manufacturers of this pipe admit that the cost is significantly lower than the installation price. They are currently considering this pipe for agriculture, irrigation and other commercial applications.

Manufacturers and Suppliers

Danby™ (PVC)

Rib-Loc (PVC)

Summary

The pipe technologies and prices are summarized and listed in the following table.

Table 2-1
Pipe Lining Technology

Technology	6-Inch (152.4 m) Diameter	10-Inch Diameter (254 mm)
Fold and Form	$32 - $35/ft ($105-$115/m)	$40 - $45/ft ($130-$150/m)
CIPP	$30 - $42/ft ($105-$140/m)	$50 - $70/ft ($165-$230/m)
Spiral Wound	$30/ft ($100/m)	$50/ft ($165/m)

The spiral wound pipe technology requires no modification and is most easily adaptable to the electric transmission cable trenching application. This system could easily be adapted to the narrow trench application and operated by workers with very little technical training. The spiral wound liner technology is very simple and uncomplicated when compared to the other technologies that require sophisticated heat curing systems, long cure times, additional equipment and special training.

3
DUCT LINERS AS FORMS FOR CONCRETE-ENCASED DUCTS

Introduction

Aligning and joining four to eight 10-20 foot (3.048-.6.096 m) long duct sections in a typical duct bank is the most time consuming activity during the civil works, and is usually the critical path item in terms of trench opening time.

In addition, the presence of an 0.25-inch (6.35 mm) wall of high thermal resistively PVC or polyethylene reduces ampacity slightly – about 10 amperes for a typical 138-kV circuit.

A method to form longer duct lengths rapidly, with minimal labor, will result in lower costs and faster installation.

A thin-wall liner can be used as a former for the concrete envelope.[2] Several hundred feet of this liner can be placed on a reel. Although it may be feasible to place three six-inch (152.4 mm) liners in the trench, on balance installing one ten-inch liner (254 mm) is preferable. Both approaches are described. Once the liner is in place (and held in place with spacers if needed), it is pressurized to make it cylindrical, and to withstand the pressure of the concrete as it is poured and before it sets. The concrete envelope is then poured. It is possible to deflate and remove the liner after the concrete sets.

These thin-wall liners, commonly called U-liners, are used to rehabilitate leaky gas or water lines. The liner is folded into a U and inserted into the existing leaky pipe. It is expanded and heat-set, and used as a leak-tight liner.

This system has the advantages of:

- Shorter street opening times
- Ability to thread among cross services
- Potentially lower cost

[2] Credit for originating this concept goes to Rusty Bascom of PDC.

Applicable Routes

This approach appears applicable to any route. We envision the ability to thread the U-liner among services which may cross the trench – although we recognize that pouring the concrete envelope may require setting forms. This operation could offset the savings in duct placement.

The economics and installation times are improved with longer trench-opening distances.

Installation Issues

Slip-liners

Chapter 2 describes the slip lining approach in detail.

Application

Steps in applying the thin liner duct are expected to be as follows:

1. Open 200 – 400 feet (61-122 m) of trench in conventional fashion. Place forms in the trench if needed
2. Pull the U-liner from a reel into the trench
3. Thread it through cross services if needed
4. Place spacers as needed to keep the U-liner in the proper position and to keep it from floating as concrete is placed in the trench
5. Pressurize the U-liner with air or perhaps water to inflate it and make it cylindrical. Set pressure to proper level to prevent herniation, but also to prevent collapse when concrete is poured around it.
6. Pour concrete into trench (Possibly use a thick plastic liner or precast concrete slabs for sides/top)
7. After the concrete has cured sufficiently, remove forms (if used), backfill as necessary
8. Deflate the U-liner. If feasible, remove it for re-use.
   If the U-liner is to remain, fill it with steam or hot water to “set” it into round shape. Possibly, the heat of hydration of the concrete can set the material

Joining Adjacent Sections

After the first 200 – 400 foot (61-122 m) section is completed, that section would have to be air- or water-filled to round-out the duct for subsequent sections. This is inefficient. Methods of handling subsequent sections should be investigated. The simplest method is to simply leave 6-8 (1.83-2.44 m) feet open between each section. After the two adjacent sections are completed and concrete set, a split sleeve could be placed over the exposed duct ends, and concrete poured around that sleeve.

Six-inch (152.4 mm) or Ten-inch (245 mm) Duct

Most extruded-dielectric cable installations use individual 6-inch (152.4 mm) ducts, with the cables pulled into their respective ducts one at a time. Reels of 5-inch (127 mm) or 6-inch (152.4 m) U-liner will be smaller and easier to handle than reels of 10-inch (254 mm) U-liner. However, aligning three ducts for a single-circuit system or six ducts for a two-circuit system will be difficult, and may even be as time-consuming as handling rigid duct.

A ten-inch (254 mm) plastic duct will handle even large conductor size 138-kV cables. This is a simpler and less expensive installation, and it will have a lower magnetic field. This approach has two disadvantages relative to individual six-inch (152.4 mm) ducts, however.

- Ampacity will be lower: As shown in Section 5, ampacity for a 750 kcmil aluminum-conductor cable will be about 560 amperes, versus 600 amperes for individual six-inch (152.4 mm) ducts.
- It will not be possible to replace a single phase, as can be done for individual ducts. However, the performance of extruded-dielectric transmission cables has been extremely good. If there were a cable failure, the failure location would be determined, and repairs made at that spot – just as for a pipe-type cable.

Bends

Typical duct installations require minimum 30 – 40 foot (9.14-12.19 m) bend radii for 6-inch (152.4 mm) duct, and 60-80 feet (18.28-24.38 m) for a 10-inch (254 mm) duct. It may be difficult to make these bends without a tendency for the U-liner to bend or buckle. This issue will have to be addressed.

Coefficients of Friction

If the U-liner stays in place, the coefficient of friction will be the established value based upon the duct material and the cable jacket. If the U-liner is to be removed, we anticipate that a smooth concrete face will be presented. However, if the concrete face is not acceptable, it should be possible to pull an epoxy-coated swab through to give a smooth epoxy coating inside the duct.

Cross-Sections

Proposed trench cross-sections for the two slip-liner approaches are presented below:

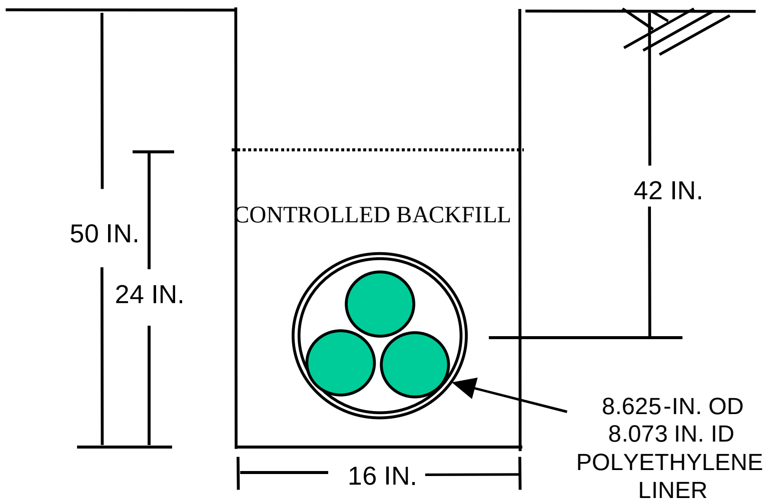
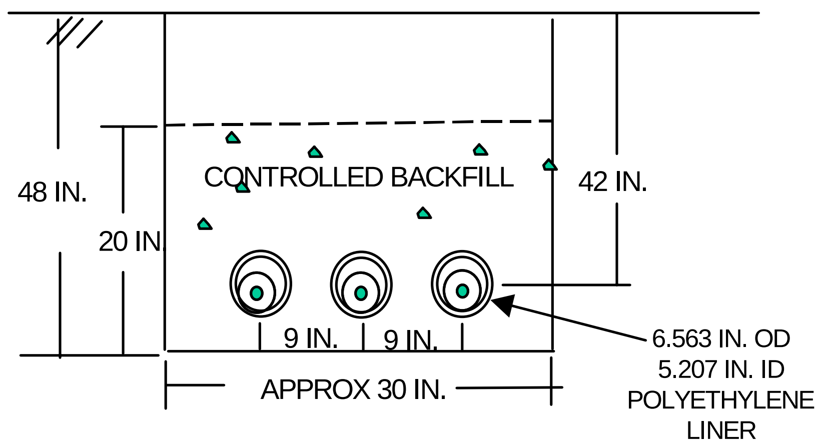


Figure 3-1
Three cables in one slip-lined concrete envelope



Revise this for 6-in ducts

Figure 3-2
Cables each in their own slip-lined duct

Equipment Issues

The equipment for placing the U-liner is commonly used in the gas industry. Translation of the technology to the electric industry should be straightforward.

Once the duct is in place, installing cable in the duct should be no different from procedures for conventional duct systems.

Ampacity

Ampacity calculations were performed for the base-case trench cross-section identified in the Plowing section, and for the two potential slip-lined configurations. Results are summarized in Table 3-1.

Table 3-1
Ampacities, Conventional

And Slip-lined Installations

	Conventional	Three-in-One	Single Ducts
750 kcmil Al			
Cross-bonded	610 A	555 A	600 A
Multi-point bonded	500 A	535 A	505 A
1500 kcmil Cu			
Cross-bonded	1165A	900 A	1130 A
Multi-point bonded	725A	830 A	720 A

As can be seen in Table 3-1, the three cables in one duct reduces ampacity by 7 – 13%, depending upon conductor size and cross-bonding method. Single-cable per duct has only a slight reduction.

Cost

As described in Chapter 2, the price for individual six-inch (152.4 m) ducts for the various slip liner applications range between $30-42 per foot ($100-140 per meter). This is much higher than the $5 – 10 per foot ($16-33 per meter) for conventional rigid PVC installations. Significant installation efficiencies would have to be developed to make this approach viable. If we can use five-inch (127 mm) ducts, the price would be somewhat lower, but probably still higher than for a conventional installation.

The installed price for a ten-inch (254 mm) diameter slip-lined system ranges between $40 - $70 ($130-230/m) per foot. We do not have price comparisons for ten-inch PVC (254 mm) or polyethylene ducts. However, the installed cost for a ten-inch (254 mm) steel pipe is approximately $35 per foot ($115/m), so the slip-liner installation is similar. Installation efficiencies could reduce the cost below that for a steel-pipe installation, and ampacities will be higher, by 10 – 20%.

Summary

The approach of unrolling a long section of duct former, then using it as a mold for a long duct section has definite merit. Simply taking existing technology for the pipeline industry and applying it to the electric utility industry does not appear to offer major cost advantages. However, there seem to be opportunities to adapt the pipeline approaches to underground cables with possible significant cost reductions.

4
FAST MICROTUNNELING EXCAVATION PROJECT

Executive Summary

Microtunneling is a trenchless construction process developed for the wastewater industry whereby small diameter holes are bored horizontally underground using machines that are remotely operated to avoid the disruption and cost of open trenching.

Microtunneling, which was originally developed for the gas and sewer industry, has significant potential for improvements and cost reduction when applied to the electric transmission and distribution industry. Improvements to microtunnleing can be realized in the following areas:

- Improved pipe handling
- Increased spoils extraction rate
- Reduced steering requirements
- Improved cutter head design

These improvements and modifications can result in installation rate increases of 2-4 times with a significant reduction in installation cost. This study explains the microtunneling method, provides a benchmark for existing tunneling operations, describes the design modifications needed for improvement and estimates the excavation rate improvements and cost reductions for a typical electric transmission cable casing installation. This report also outlines a development program to modify and field test a microtunneling machine to demonstrate these concepts and improvements.

Table 4-1
Microtunneling Comparisons

	Benchmark	Est. Improvement
Hole Diameter	30 Inch Diameter (762 mm)	30 Inch Diameter (762 mm)
Hole Length	600 feet (183 m)	600 feet (183 m)
Soil	Glacial Till	Glacial Till
Mean Boring rate	25 ft/hr (0.00212m/s)	50 ft/hr (0.00424m/s)
Price	$565/ft ($1850/m)	$377/ft ($1240/m)

Introduction

The objective of this study is to investigate the potential to increase the rate of microtunneling for small diameter holes to reduce the cost for electric transmission cable installation applications. This study will be accomplished by identifying and describing those steps in the microtunneling process that are the most time consuming. Several design improvements will be identified and an estimate will be made of the cost to perform these modifications and the improvements that will result.

The utilization rate of microtunnel boring machines (MTBMs) is nominally in the 25 - 35% range at best. This means that the MTBM is actually boring and making progress only 25 - 35% of the shift time. By contrast, modern large bore tunneling is accomplished routinely at 50% and the best rates have been in excess of 60%. Microtunneling can achieve similar rates with subsequent reduction in excavation cost by applying some novel techniques and methods to four areas of the microtunneling process:

- Pipe handling and loading
- Steering
- Spoils/muck removal
- Cutterhead design

Background

Microtunneling is classified as one of the new Trenchless Technologies. Microtunneling is a trenchless construction process developed for the wastewater industry whereby small diameter holes are bored horizontally underground using a machine that is remotely operated. Microtunneling avoids the disruption and cost of open trenching especially in highly developed suburban, commercial and industrial areas.

Trenchless Technology is a term that describes the installation, refurbishment or replacement of underground utility infrastructure using construction methods that avoid the disruption, cost and inconvenience of open trenching. The trenchless technology revolution in the construction industry over the last decade has come a result of six factors:

- rapidly decaying underground infrastructure in need of replacement or repair
- the demand for additional underground utility capacity in developing areas
- the congestion of commercial, residential and industrial developments
- the desire to avoid visual pollution by installing all new utilities underground and converting old overhead utilities to underground installations
- the high social cost of open trenching operations
- the high cost of surface restoration from open trenching

The demand for new and improved trenchless technology has spawned the use of many new construction methods. Some of these new methods are still in their developmental infancy and are currently being applied only to their initial market application. Significant improvements can be made to this technology to benefit other industries and applications such as the electric transmission industry.

Microtunneling Process

Microtunneling is a process by which a remote controlled tunneling machine is driven from a drive shaft or pit by means of hydraulic cylinders or jacks to an exit pit or shaft. The tunneling machine is launched horizontally from a pit through a steel entrance ring, placed against the pit wall. The entrance ring isolates and stabilizes the ground from the pit. Excavated soil is carried by a bentonite slurry mixture from the face of the machine to the surface where it is cleaned and recycled. Ground pressure in front of the machine is equalized with slurry and jacking pressures. As the tunneling machine and pipe are jacked forward by the hydraulic cylinders, a new pipe is added onto the back of the previous section of pipe. The pipe is a thin wall pipe that is slightly smaller than the machine diameter. This pipe remains in the hole as the final product pipe once the machine reaches the receiving or exit pit. Microtunneling can be used where precise grade must be maintained such as gravity sewer applications. It is also particularly well suited to problem ground situations where the installation is deep, there is unstable soil or rocky ground. Diameters of 12 inch (304.8 mm) to 12 feet (3.65 m) can be installed in this manner in distances up to 1500 ft. (460 m) Figure 4-1 shows a cross-section of a typical microtunneling operation.

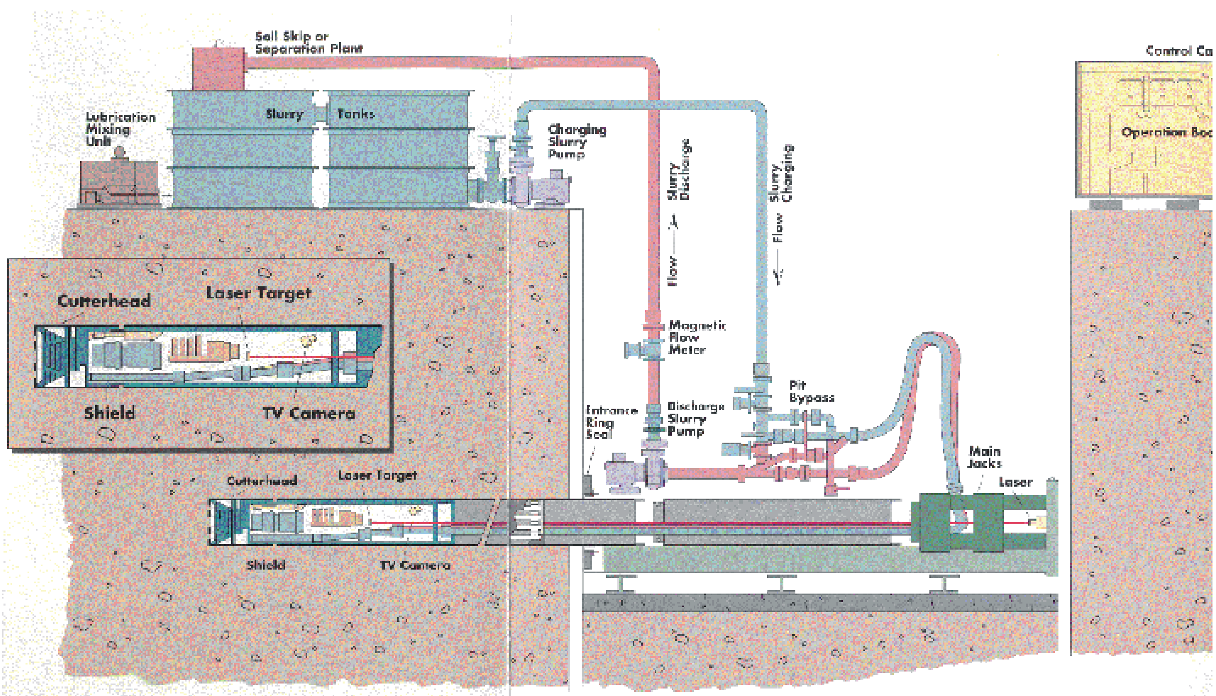


Figure 4-1
Typical Microtunnel Process and Equipment

Operation Sequence

The operation sequence of a microtunneling project is listed as follows:

- Excavate the starting pit to just below the grade of the intended pipe installation alignment.
- Construct machine launch pad and backstop.
- Lower machine and thrust frame into pit with first section of pipe.
- Connect electrical and fluid connections to the machine.
- Place the thrust ring on face of pit.
- Align the laser guidance system with the desired alignment of the pipe and with target on the microtunneling cutterhead.
- Begin jacking and boring the first section of pipe.
- Steer the cutterhead to stay on alignment by varying thrust on the steering cylinders.
- Cuttings are mixed with bentonite fluid at the face and pumped to the surface where they are cleaned in shakers and hydrocyclones and recycled to the face.
- As each section of pipe is bored and jacked into the tunnel an additional 10 - 20 ft pipe section is added.
- Machine steering, thrust and rotation operations are all remotely controlled from the surface. Workers in the pit disconnect the slurry, hydraulic and electric lines after each push and reconnect these lines after each new pipe section is added.
- An exit or receiving pit is excavated in time to receive the machine at the completion of the drive.
- The machine is removed from the exit/receiving pit and the pipe remains in the hole as the final product pipe or casing.
- The support equipment is moved to the exit/receiving pit and the machine it is either redirected in a new alignment or continues on the existing alignment to complete the next drive.

Guidance and Steering

Guidance is achieved by the use of a laser that is mounted on the back of the entrance pit wall and sighted along the intended pipe alignment. The laser strikes a target on the back of the microtunneler cutterhead. Any variance in the machine alignment is immediately apparent on the target. A remote video camera mounted inside the machine relays an image of the target and laser to the operator located in the control room at the surface. Variations from the intended path are corrected by making small corrections to the angle of the cutterhead as the machine advances. This is done by varying the pressure in the steering cylinders that slightly tilt the cutterhead.

Machine Advance and Pipe Installation

The machine is advanced by large cylinders located in the entrance pit. These cylinders are mounted in a frame that thrusts the machine and pipe forward into the tunnel. The cylinders and frame push against the backside of the entrance pit and advance the pipe and microtunneling machine forward. The pipe does not rotate as it is advanced forward only the cutterhead rotates. After each pipe section is pushed into the tunnel an additional section is added to the back of the previous section and the process repeats. At the end of the drive, the thrust cylinders are pushing all the pipe sections and the microtunneling machine forward. The force increases as each additional section is added. Bentonite fluid is frequently pumped into the annular space between the hole and the pipe to reduce the jacking force.

Soil Excavation

The soil is cut by the microtunneling machine cutterhead. The head rotates independent of the machine and pipe. As the head rotates it cuts the soil and mixes the soil with bentonite fluid that is pumped into the space between the cutterhead and the face. The bentonite fluid performs the function of transporting the cuttings to the surface. The bentonite mixture is pumped from the face to the recycling system where the cuttings, sand and silt are removed.

The tunneling machine and pipe do not rotate and always maintain a constant orientation with the tunnel as they are pushed from the entrance pit to the receiving pit. The cutter head is usually designed for a specific soil type.

Primary Areas FOR MTMB Improvement

The four major elements of a typical MTBM system that are most responsible for the low utilization and penetration rates are as follows:

- Pipe and utility handling
- Spoils/muck removal
- Steering
- Cutterhead design

Pipe Loading and Handling

Lowering a new section of pipe into the launch shaft, stringing and connecting the utility bundle and making the piping connection is the largest contributor to non-excavating time. Further, in many setups to save space, the thrust cylinder stroke is designed to stroke only half the pipe length. The newly added pipe section is pushed halfway into the tunnel, the cylinders are retracted, a spacer is placed behind the pipe section and the last half of the pipe is jacked into the hole. The spacer must be removed to make way for the next pipe section.

Utility piping and wiring are disconnected, strung through the new section of pipe land re-connected. This is time consuming and prone to error due to the many connections that must be made.

Potential improvements to this system are as follows:

a. Minimize the utility bundle, and utilize an external utility channel built into the wall of the pipe as shown in Figure 4-2. Thus the entire bundle can be in a single coil with no splices or connectors thus avoiding the time required to break and make new connections each time a pipe or spacer are added.

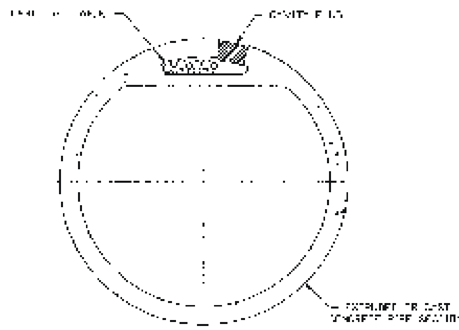


Figure 4-2
External Umbilical Bundle Concept

b. Handle new pipe sections by means of an elevator gantry and load pipe sections with a semi-automated placement arm. Lowering pipe sections in a vertical orientation by elevator, located close along side of the shaft wall would insure that the next pipe section is close at hand. At the shaft bottom, pipe could be lifted from the elevator, moved to horizontal, and fed into position by means similar to the handling of segments in a large tunnel bore. One of the most successful methods of lifting segments has been the use of vacuum. An arm with suction cups holds the pipe securely without the necessity of fasteners. This concept is shown in Figure 4-3.

A side benefit of this concept is a significant improvement in operator safety.

c. Pipe sections should be designed to snap or latch together, and seal by an o-ring. This should be accomplished in such a manner that:

   1. In an emergency situation, pipe sections can be pulled out of the hole, and

   2. The joints should retain a minimum amount of flexibility.

d. Spacers (short pipe sections installed temporarily for jacking the second half of the pipe) should be eliminated. There are several ways to accomplish this task including:

   1. Powered rack and pinion (cog railway) system that provides a full stroke.

   2. Multiple short cylinders that provide a complete stroke in less space than a single cylinder.

   3. Walking cylinders that can re-grip the pipe frame for additional stroke.

   4. A mechanical linkage system that allows the shorter cylinders to stroke the full length of the pipe.

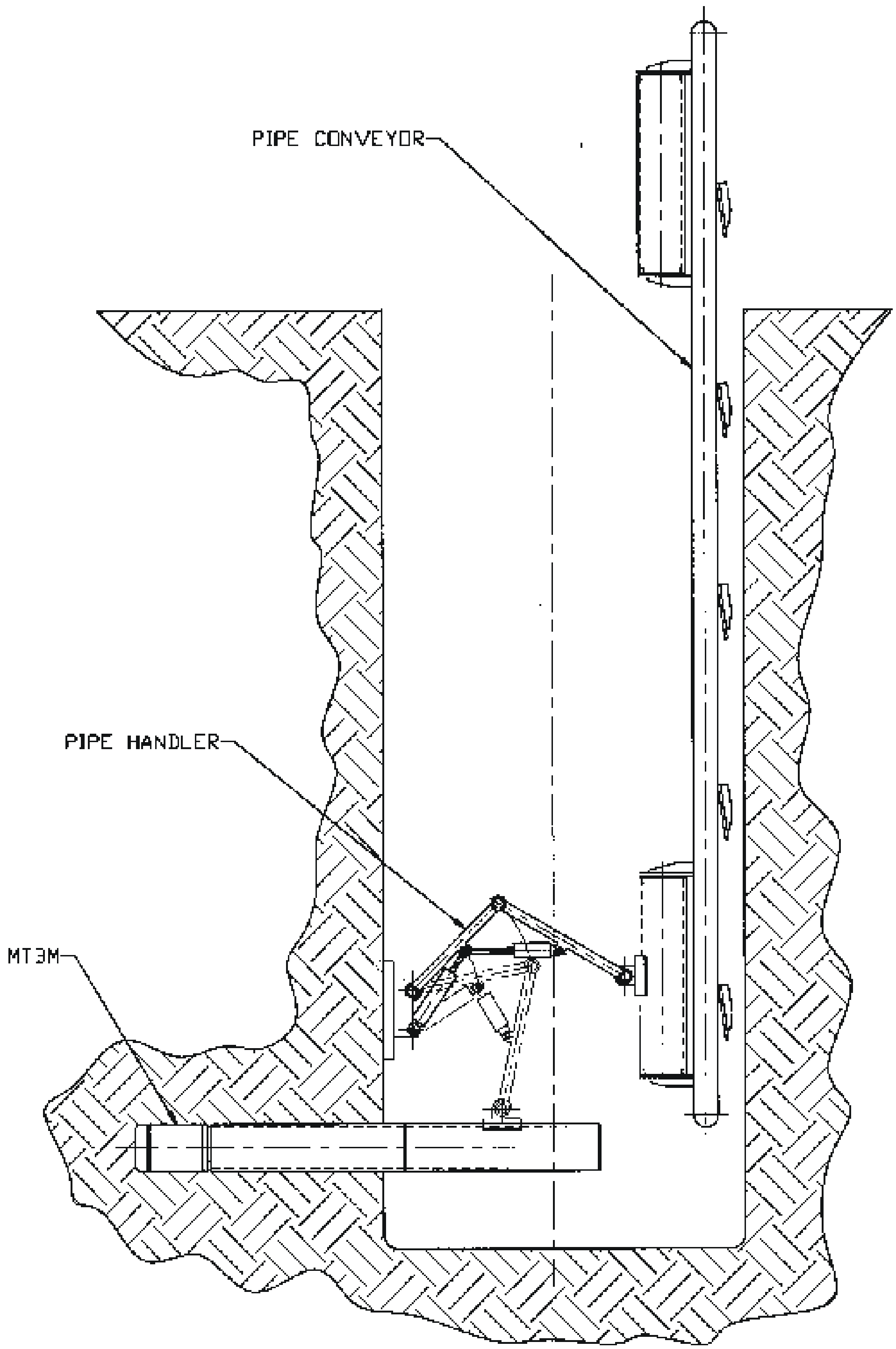


Figure 4-3
Pipe Handling and Loading System

Spoils/Muck Handling

The vast majority of MTBM systems use a slurry muck removal system. This system requires that 95 lbs. (43.09 kg) of fluid be pumped to the face to remove 5 –10 lbs. (2.26-4.52 kg) of cuttings. This system consists of mud pumps, shale shakers and hydrocyclones to remove sand and silt. The system also includes mud tanks and a drilling mud mixing system.

To improve machine advance rate with muck removal by slurry, fluid volumes must be increased and fluid lines and separation systems enlarged. This improves the machine advance capability but complicates all other aspects of slurry removal.

Ideally, a dry system, or at least an Earth Pressure Balance (EPB) methodology is preferred. If a dry system can be developed, only a few gpm of fluid for dust suppression.

At least three methodologies can be considered for spoils or muck removal as follows:

a. **Vacuum – Pneumatic** - A vacuum pump is located in the shaft and, at the face the rotation of the cutterhead feeds the mouth of the system. At the shaft bottom, the material goes through a drop box, exits by means of a star feeder and converts to a pressure pneumatic system to lift the cuttings to surface. Converting to pressure in the shaft reduces power requirements and keeps the noise producing equipment below surface.

b. **A Pressure Pneumatic System** - In this methodology, rotation of the cutterhead feeds a star feeder, which expels the cuttings into a pressurized pipe. The compressor is ideally located at the machine, but could also be located in the shaft or on the surface. The latter two locations require a high-pressure air line to be included in the umbilical bundle; where as if the compressor can be located in the hole, only the electrical connection is required. A drop box for spoils is located on the surface.

   Note: Either of the two pneumatic systems described above automatically solves the tunnel ventilation problem. Both systems draw air from the face area and fresh air is drawn in through the tunnel. This system is shown in Figure 4-4.

c. **Conveyor Belt** - In this methodology, rotation of the cutterhead feeds a small belt conveyor that transports the spoils inside the pipe to the starting pit. This belt must feed another system that moves the spoils vertically out of the pit to the surface. The most difficult element in a belt system is the method of supporting the belt in the tunnel connecting additional sections of belt with each addition of pipe.

   The belt system is probably the least promising of the methodologies because it is mechanically complex and requires a great deal of space. However, because the system is dry and requires the least amount of power it merits discussion.

d. **Earth Pressure Balance (EPB)** - This system requires the injection of a conditioning fluid (water with additives) but at a much lower volume than a slurry. Ratios by weight, for an EPB are in the range of 10 to 20% by weight fluid and 80 to 90% by weight cuttings. The cutterhead feeds a screw conveyor, which discharges into a positive-displacement mud pump. The pump discharges into a pipe going to the surface.

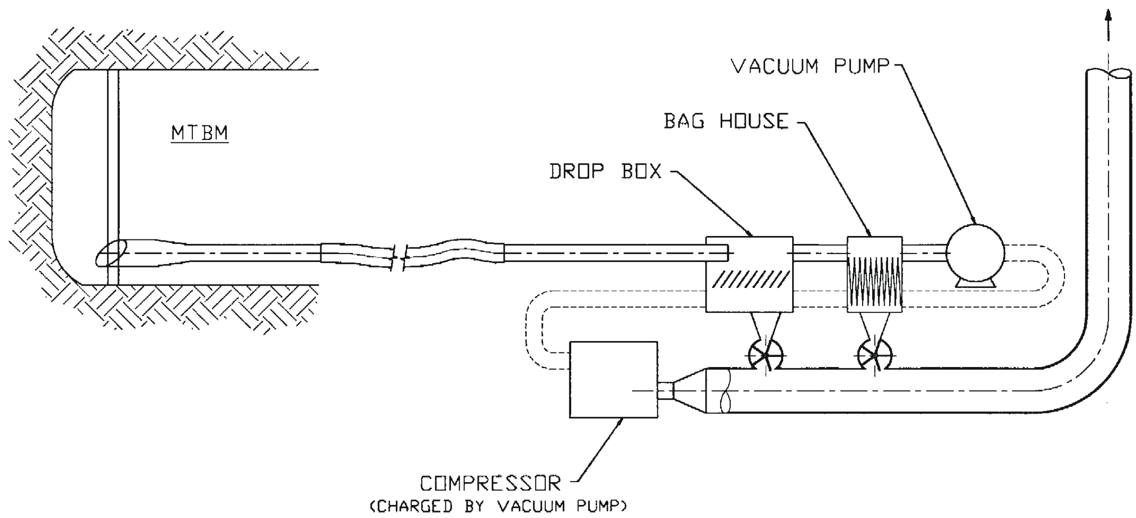


Figure 4-4
Vacuum/Pressure Spoils Transport System

Steering

The steering on an MTBM, compared with other forms of tunneling machines, is minimal. Steering is intended to maintain a straight line. Mechanically, the methodology is well established and satisfactory. It requires additional time primarily because it is an action requires a great deal of thought and is subject to error. Steering systems consist of a laser beam striking a target located as far forward on the machine cutterhead as practical. A TV camera or CCD system provides the operator with information on the location of the laser on the target.

The problem with this system is that it provides the operator with information about where the machine is, not where it is going. Operators tend to over-steer the machine resulting in a sine wave alignment, which oscillates about the intended alignment. If carried to extreme, the result can be an increase in thrust until the pipe becomes jammed or collapses under a high compressive load. Since this usually occurs near the end of a tunnel, it can be a major setback.

A three point hydraulic steering system, which pivots the cutterhead a few degrees, has been shown to be a mechanically satisfactory system. The technology is available to provide a three- dimensional guidance system which displays, not only where the machine is, but also its alignment with respect to true line and grade (where it is heading).

Machine geometry and shaft alignment is programmed into the steering system, which contains a feedback loop from the laser target. The program projects the alignment target several meters in front of the machine. Without even realizing it, the operator is following the projected target. The sine wave motion diminishes dramatically and the potential thrust build up diminishes proportionately.

This steering system can be automated by automatically metering oil to or from the appropriate steering cylinders in response to the location of the projected spot. This added automation removes the routine judgment from the operator. It requires the operator to monitor, and respond to the unusual or emergency situations only.

Cutterhead Design

Compared with large TBMs, use of the MTBM is a relatively new art that is just now being accepted by the wastewater industry. A number of the problems plaguing the MTBM have been solved in larger machines. In fact, a number of the issues described previously can find solutions by adapting larger TBM technology.

Microtunneling had its origin in soft, near surface ground or soil. Expectations have grown to the point where MTBMs are now being used in difficult ground conditions such as solid rock, broken rock and mixed ground containing soil, solid rock, boulders and cobbles. There have been innumerable examples where a soft ground cutterhead was used in inappropriate ground conditions. This invariably leads to a stuck and broken machine, a jammed cutterhead and expensive and a disruptive rescue effort. When this occurs the unplanned pit must be excavated directly over the machine, many times in an inappropriate location to rescue, fix or remove the machine.

Cutterheads have been designed that include a cone shaped rock crusher to accommodate cobbles and small boulders. These designs are frequently unsuccessful and result in many failed projects from the cutterhead becomes stuck. With one exception, all MTBMs use a simple converging cone crusher with a single rotating member. This configuration employs an open cutterhead configuration that does not control the size or feed rate of material into the machine. This configuration repeatedly fails when solid rock, boulders or cobbles are encountered.

In contrast, large TBMs have been designed to work in these conditions. TBM technology has been field proven and can be easily adapted to the smaller MTBMs. Features of this design include:

a. Electric, dual-range variable speed drive. High speed is desired for solid conditions and slow speed for broken rock and cobbles.

b. Ample cutter head power.

c. Deeply recessed single disc cutters, backed by teeth. When soft ground is encountered the disc cutters simply sink in. The teeth, arranged in scoops, take over to perform the cutting. When solid ground or a boulder is encountered, the disc-cutters contact the hard object first. The disc-cutters split the rock and produce chip-like cuttings.

d. A cutterhead design, which is reversible, but cuts in only one direction, provides additional control. Reversing the head slows the spoils intake by “troweling” the tunnel face. Turning the head in the cutting direction aggressively feeds the cuttings into the head.

e. Radial slotted intake openings control the size of cuttings that can pass through the cutterhead. In combination with the disc cutters, relatively narrow slot openings grade the material entering the muck removal system. Head speed and direction of rotation control the volume entering the system. With these two features, a crusher becomes redundant.

A redesigned cutterhead that was used in a mixed soil tunnel consisting of solid rock, broken ground, and boulders. This 1.25 m diameter machine averaged 12.5 ft/hr (0.001058 m/s) over the length of the drive with a maximum advance of 22 ft/hr (0.001863 m/s) in the solid rock. The machine was hampered only because of a slurry return line that was too small for the machine size.

For best results, this advanced head design should be used in combination with a muck/spoils removal system that can provide increased flow rate and accommodate the largest cuttings possible. Power is wasted in producing excessively small cuttings and results in slower advance rates. This cutterhead is not ideal for all conditions, but it will successfully excavate a much wider range of soil and rock conditions than current designs.

Benchmark Microtunnel Project

Two drives from a current microtunneling project were selected as the benchmark. The project was completed by Frank Colluccio Construction Company of Seattle, WA for the Seattle Metro Sanitary Sewer District. The Seattle Metro awarded this project in a competitive bid process. Two drives from this project were documented and studied. The drives were performed in sequence along the same tunnel alignment in identical soil.

The project activities were well documented by engineers on the site who recorded time to the nearest minute. The project activities and data categories documented were as follows:

- Machine OD
- Pipe OD
- Date
- Pipe Number
- Start-Finish Time
- Slurry Flow Rate
- Pit By Pass
- Machine By Pass
- Face Pressure
- Machine Center
- Steering Indicator
- Pitch
- Earth Pressure
- Steering Jack Pressure
- Torque
- Speed
- Main Jack Force
- Intermediate Jack-1 Force

- Intermediate Jack-2 Force
- Roll
- Head Rotation
- Slurry Specific Gravity
- Slurry Viscosity
- Comments, Delays, Etc.

Construction log entries were made in nearly every category for the start and finish of each section of pipe. The pipe sections were each 10-ft long (3.048 m).

Microtunnel Drive 1

Machine No. TCL 800
Drive length 630 ft (192.0 m)
Pipe OD – 978 mm (38.5 inches)
Pipe ID – 762 mm (30 inches)
Machine OD 1000 mm (39.37 inches)

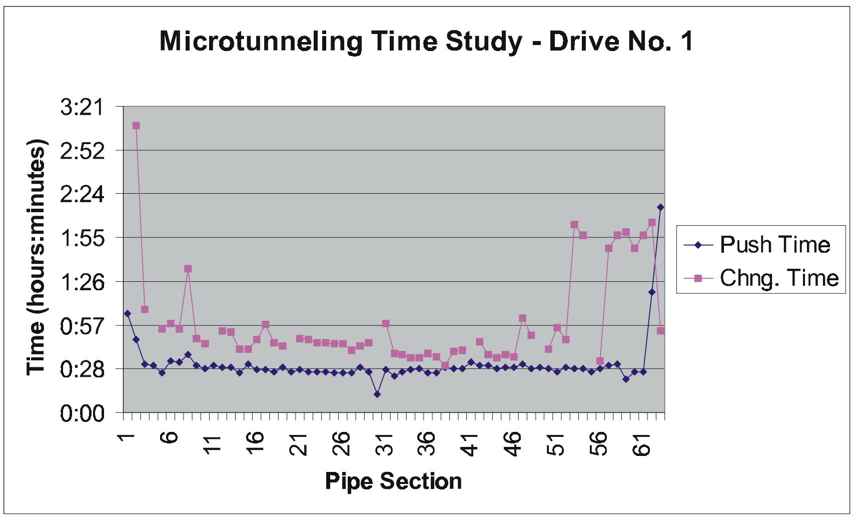


Figure 4-5
Microtunneling Time Study – Drive No.1

This drive was completed over a period of 11 days, 9 of which were working days, from July 16, 1999 to July 27, 1999. The mean time for each push (excavation) was 32 minutes while the mean time for each pipe change was 59 minutes 45 seconds. Over this entire drive 34.9% of the time was spent excavating soil while 65.1% was spent adding a new section of pipe. The excavation times remained relatively constant but the time required adding new pipe seemed to decrease slightly as the drive progressed. There is no apparent explanation for this decrease because this was an experienced crew.

Microtunnel Drive 2

Machine No. TCL 800
Drive length 430 ft (131 m)
Pipe OD – 978 mm (38.5 inches)
Pipe ID – 762 mm (30 inches)
Machine OD 1000 mm (39.37 inches)

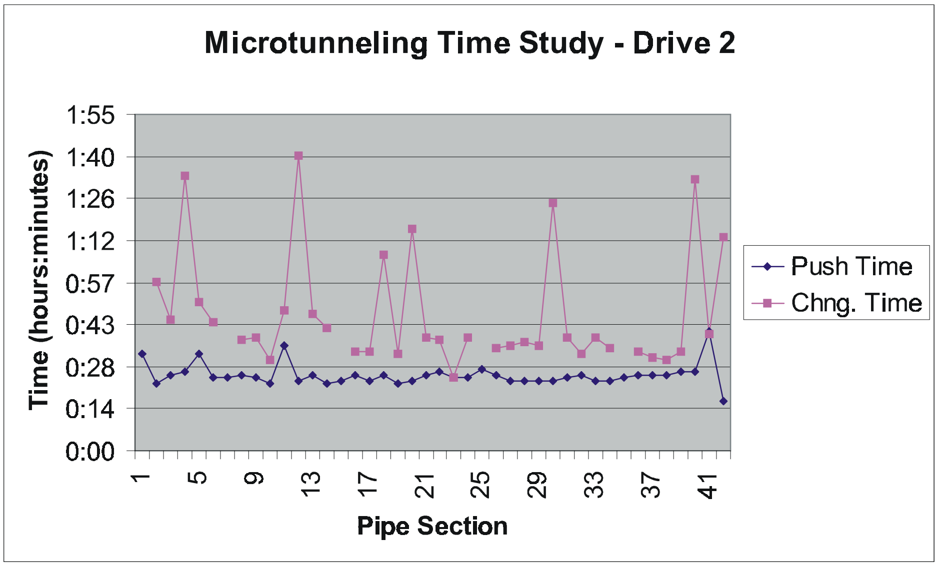


Figure 4-6
Microtunneling Time Study – Drive No.2

This drive was completed over a period of 9 days, 6 of which were working days, from August 4, 1999 to August 12, 1999. The mean time for each push (excavation) was 25 minutes 56 seconds while the mean time for each pipe change was 46 minutes 54 seconds. During this drive 35.6% of the time was spent excavating soil while 64.4% of the time was spent adding a new section of pipe. The excavation times remained relatively constant but the time required adding new pipe seemed to vary greatly during this drive.

The summary table for the two drives is as follows:

	Push Time	Percentage	Change Time Percentage
Drive 1 32:00	34.9%	59:45	65.1%
Drive 2 25:56	35.6%	46:54	64.4%

This benchmark reveals that nearly twice as much time was required to install and load a new pipe section as was required to bore the soil. There is significant opportunity for improvement in the pipe loading time that will increase productivity on a typical project. This will result in a significant reduction in installation costs.

This project was bid at a price of $564/lineal foot ($1850/lineal meter) and completed on time. This price included all excavation and materials to complete the installation.

Cost Benefit Analysis

Table 4-2 shows a summary of the actual costs for the benchmark 30-inch (0.762 m) diameter microtunneling project and the estimated cost reduction resulting from improvements in productivity. The productivity estimates are based upon the following estimates:

- Pipe handling and loading — 50% reduction in pipe loading time
- Increased spoils removal — 15% reduction in jacking time
- Cutterhead design — 15% reduction in jacking time
- Steering improvements — 20% reduction in jacking time

These improvements have been conservatively estimated to reduce overall microtunneling time by 50%.

Table 4-2
Cost Benefit Analysis for Microtunneling Improvements

Benchmark Microtunnel Project Cost

	Cost/ft (Cost/m)	Type	New Cost/ft (Cost/m)	Savings
Material and Consumables	$138.65 ($454.89)	Fixed	$ 38.65 ($454.89)	
Labor	$114.93 ($377.07)	Variable	$ 57.47 ($188.55)	
Eqpt.	$158.48 ($519.95)	Variable	$ 79.24 ($259.97)	
Fee and Overhead	$152.46 ($500.20)	Variable	$ 101.88 ($334.25)	
Total	$564.52 ($1852.11)		$ 377.24 (1237.66)	$ 187.28 (614.45)

The proposed modifications will increase the productivity of the microtunneling operation and reduce costs by a significant amount. The cost reduction for a 30 inch (762 mm) diameter casing installation will be $187.28 ($614.45) or 33% cost savings. This represents a significant cost saving for trenchless excavation technology, which already presents many advantages over convention excavation technology in highly congested suburban, commercial and industrial areas.

5

AUGER BORING TECHNOLOGY INTERSECTIONS

Introduction

Auger boring is a common technology employed for shallow and short road boring, highway crossings and stream crossings. It has been used effectively for years to place pipes and casings under roads, highways, landscape and various concrete structures where open trenching is not practical, cost effective or desirable. Auger boring is both cost-effective and practical for a wide range of soil types and applications.

The installation of underground electric transmission cables in highly congested city streets and downtown locations is complicated by the requirement that long trenches be opened to make the process more cost effective. Intersections present a unique problem with traffic disruption that is particularly costly. When an intersection is open trenched, traffic is disrupted in both directions, causing problematic re-routing and traffic control and resulting in high social cost. Trenching between blocks usually requires closing only one traffic lane and the parking lane. This costly intersection closing can be avoided by employing auger boring technology for the intersection crossings in conjunction with open trenching between intersections.

Auger Boring

Auger boring was developed in the early 1950's to aid oil companies in making short road crossings while laying long underground pipelines. This was done to prevent costly and disruptive open cutting of roads. This technology adapted guidance systems from the directional drilling industry and rudimentary steering control even though they are seldom used in short distance applications. Auger boring is frequently used for hole diameters from 6-inch (152.4 mm) to 36-inch (914 mm) and has been applied to applications ranging from 2-inch (50.8 m) diameter to 60-inch (1.524 m) diameter.

Auger boring is performed by a machine that is launched from a pit along the intended alignment of the pipe that will be installed. The machine as shown in Figure 1 consists of an engine or hydraulic power unit mounted on a frame. The power unit or engine drives an auger through a gearbox that allows the auger to be disengaged from the engine. The gearbox also provides the ability to vary rpm and torque of the auger. The auger is usually operated inside the casing pipe that will be installed during the hole excavation. Cutter teeth are mounted on the leading edge of the auger to cut the soil. The soil is trapped in the auger flights as it is cut and transported, inside the casing, back to the launch pit.

The entire machine is mounted on I-beam rails and is moved forward and back by hydraulic cylinders. When boring into a hole the thrust of the auger head against the soil is resisted either by the back wall of the trench or the machine must be staked or anchored into the bottom of the pit.

Operation Sequence

A typical operation sequence for an auger boring operation is as follows:

- Excavate a machine launch pit to a depth just below the grade and slope of the intended pipe alignment.
- Place and anchor the auger-boring machine into the pit.
- Attach the first auger assembly and casing pipe onto the front of the auger-boring machine.
- Align the machine and begin the boring process.
- Once the machine has advanced the first section of auger and casing into the hole, the auger drive is disconnected, the machine is retracted, leaving the auger and casing in the hole.
- A second section of auger and casing is attached to the machine and the auger already in the hole and boring resumes.
- Excavated soil (spoils) are transferred by the auger to the front of the launch pit.
- The spoils are removed from the launch pit either by manual labor or by a secondary vertical auger that transfers them to the surface.
- When the auger reaches the exit or recovery pit the auger is removed from inside the casing pipe, which remains in the hole.
- The auger-boring machine is removed from the launch pit and the operation is complete.

Figure 5-1
Typical Auger Boring Machine

Auger boring is generally performed dry and therefore suitable for only stable ground conditions. If holes are bored in unstable soil below the water table, well-pointing must be performed and great care exercised to ensure that excavation rate matches casing advance rate. This is done primarily to ensure that soil subsidence does not occur in front of the auger cutting head.

Auger boring is usually limited to relatively stable ground conditions and short installations under 300 ft. (91.5 m) Record drives exceeding 600 ft. (183 m) have been performed but are rare due to the fact that most systems do not employ guidance or elaborate methods for ground stabilization.

Electric Transmission Application

Auger boring can be used in conjunction with open trenching operations for installation of underground transmission lines to the reduce the cost and disruption of open trenching the street intersections. Intersection crossings in cities and highly congested suburban locations are expensive and highly disruptive. When open trenching an intersection crossing, traffic is disrupted on both intersecting streets and must be rerouted. This results in a significant increase in social and in traffic control cost. The intersection can remain open by auger boring the intersection crossings simultaneously with open trenching. The process can be carried out in the following sequence:

- Excavate the auger-boring pit at one end of the block.
- Begin auger boring the intersection.
- Begin open trenching at the opposite end of the block proceeding toward the auger-boring pit.
- Complete the auger bore of the intersection without opening a pit on the opposite side.
- Remove the auger from inside the casing pipe.
- Remove the auger-boring machine from the pit.
- Complete open trenching of the block to the auger pit and connect the casing to the section already in place under the intersection.

In this manner the open trenching operation can be limited to one block at a time with the intersections installed while the open trenching is proceeding. This will keep the intersections clear and free from congestion.

Cost Benefit Analysis

Typical instantaneous auger boring rates are 30 to 60 ft/hr. (0.00254 to 0.00508 m/s). With consideration for pit digging and machine installation a more reasonable rate would be 90 ft (27.5) per shift. A typical intersection could reasonably be accomplished in one shift. Auger boring is usually estimated at $5-$9/ft-dia.-in. ($6.5-$115/m-dia.-cm) in reasonably good soil. This would constitute a price of $30-$54/ft ($98-$177/m) for the installation of a 6-inch (152.4 mm) diameter steel casing. Auger boring machines are inexpensive and relatively easy to operate. The price for a machine and auger capable of boring 4-in. (101.6 mm) to 20-in. (508 mm) diameter holes is approximately $14,000.

The advantages over open trenching for this application are the elimination of traffic control in the intersection, eliminate select backfill, eliminate compaction and pavement restoration. These costs are significant and can easily exceed $100/ft. ($330/m). Other significant but difficult to quantify savings are: reduced trenching time, less disruption and reduced social cost from traffic re-routing.

Auger Boring Equipment Manufacturers

Akkerman Manufacturing, Inc.

American Augers

Barbco

Boretec

Bor-It Manufacturing Company

Contractors Manufacturing Services, Inc.

Ditch Witch Equipment Company, Inc.

Dosco Corporation

Herrenknecht

Holt Machinery Company

Iseki, Inc.

Lovat Tunnel Equipment, Inc.

McLaughlin Manufacturing Company

Michael Byrne Manufacturing

Mills Machine Company

Robbins Company

Soltau Microtunneling

Tramac Corporation

Trenchless Replacement Services, Ltd.

Underground Equipment and Supply

Vermeer Manufacturing Company

Summary

Trenchless technology, despite all its intrinsic and cost advantages, is not the answer for every application. In highly congested areas where open trenching must be performed a combination of technologies can be used to minimize the cost and impact to the business community and public. Employing auger boring with open trenching can minimize the cost and disruption by using auger boring to cross street intersections where the disruption and congestion are greatest. Auger boring is a cost-effective technology for boring short distances that do not require great accuracy or elaborate ground stabilization. Auger boring has the potential to save, at a minimum, the cost of select backfill, compaction, traffic control and pavement restoration for intersection crossings. These cost savings have been estimated at $100/ft. ($330/m).

6

OPTIMIZATION OF XLPE TRANSMISSION CABLE SECTION LENGTH

Introduction

Several factors will be affected by the increase of the individual cable section lengths for a transmission XLPE Cable circuit:

- Number of required splices will degrease and reliability will increase
- Number of reels to be shipped to the job site
- The shipping reel will be larger making the shipping route selection to installation site a more critical
- Federal, state, and local road weight limitations and bridge height limitations
- Number of pulling set-ups will decrease and traffic flow disruptions will degrease in city installations
- The sheath voltage will increase which may require specification changes
- The pulling tension and sidewall pressures will increase

Several Items that will Allow for Longer Cable Sections to be Installed

- Develop pulling compounds with improved lubricity
- Pulling rope types
- Use of Cable Pusher during installation will lower pulling tension and sidewall pressure and allow for longer lengths to be pulled.

Table 6-1
Pulling Length Comparisons

Item	Effect	Reliability issues	Project cost effect
Larger Shipping Reels	Possible invest in new reel carriers. Select transport route for the increased size	The system reliability will be increased due to fewer splices	The installation cost may increase due to the larger reel carrier. The cable system operating cost will decrease due to fewer splice location to maintain
Number of reels shipped will be less	Less pulling set-ups and traffic flow disruptions	Same as above	Substantial savings during installation due to the less number of pulls and traffic controls.
Increase in Sheath voltage	More (better) touch protection at open sheath and cross-bonding locations	Same as above. CIGRE and ICC have formed working groups to evaluate this issue	Improved voltage protection at sheath interrupt may increase cost slightly
Use of cable pushers during installation	Will lower pulling tension and sidewall pressures.	Less concerns of pulling rope producing grooves in pipe/conduit during pulling operation	Increase cost due to cost of pushers and longer set-up time for the pulling operation
Lower coefficient of friction (COF)	Lower pulling tension and sidewall pressures	Require development work	Cost of newly developed pulling compound about 10 times cost of regularly used pulling compound.

7
EXECUTIVE SUMMARY

Visits were made to utilities and manufacturers in Denmark, Switzerland, France, and the Netherlands. Use of special installation equipment in these counties has shown an increase in productivity during the installation of transmission cables. However, this equipment may require a substantial investment by the utility or their contractors.

Usually the process of getting a permit to install a transmission cable circuit requires the approval of federal and local authorities. Citizens affected by the proposed route may also have a great deal of input in the permit process. To receive a permit for an underground circuit average time may be up to two years, and for an overhead circuit the average time may be as much as eight years, if granted.

Several innovative approaches are being researched and implemented by users and manufacturers. The terminations for both in-air and SF_6 equipment has improved, so it now will be possible to prepare one termination end of the cable at the factory and to allow this end to be pushed into the termination housing. For the SF_6 equipment manufacturers this means they can assemble and test the complete switchgear assembly prior to the cable installation which will save time.

Most new transmission cable installations employ cables with XLPE insulation up through 400 kV. Splices and terminations are of the pre-molded type and some use SF_6 gas as the filling media. Through research, innovative methods of the design and installation of splices and terminations will improve the effectiveness of undergrounding transmission circuits. The cost of undergrounding will still be substantially higher than for overhead lines. In many situations this comparison is of little value since the only option is undergrounding the circuit.

Several European innovations may be applicable to the US installation practice:

1. Direct burial
2. Trefoil installation
3. Routine directional drilling
4. Special reel trailers
5. Prefabricated cable ends for splice or termination
6. Cable pushers along cable installation route
7. Installation construction train

Introduction

To optimize the installed cost of transmission XLPE cable systems, a review of European manufacturing and installation practices was undertaken. This report discusses some of aspects of manufacturing and installation practices in Denmark, Switzerland, France, and the Netherlands.

Comparing the cost of undergrounding to the cost of overhead lines was not applicable in most instances because the installation of overhead lines was not an option. Several of the new accessory designs being developed in Europe have the potential for lowering the installed cost of transmission cable circuits.

Interviews

Interviews were conducted from May 4 through May 16, 1998 and additional information was collected during May of 1999. The information pertaining to each of the visits is discussed in the following sections.

Denmark

In Denmark meetings were held with NKT Cables, the Danish cable manufacturer, and Copenhagen Energy, the utility that serves the Danish capital of Copenhagen. The meetings were held at the NKT Cable’s XLPE cable and accessories manufacturing facility in Glostrup, Denmark.

The transmission voltage levels are 132 kV (145 kV) and 400 kV (425 kV). The cable types for the 132 kV include XLPE, three-conductor M⇑llerh⇑j construction, which is a non-pressurized self compensating paper insulated cable type, and low pressure fluid-filled cable types. Most new installations will utilize the XLPE cable type, and where it is the extension of existing circuits the original installed cable type will be used. At the 400 kV voltage level, all of the cables are with XLPE insulation.

Cross bonding is used where required to increase the current carrying capabilities. However, mid-point grounding is used more often. There is no specified sheath voltage limit, but a design voltage of 200 to 300 volts is often used. If it is not possible to meet this criterion, the area where the sheath voltage can exceed this value will be secured so access will be possible only when the cable circuit is de-energized.

The installation of transmission cable circuits in Denmark is mostly concentrated in and around Copenhagen, the capital of Denmark. About 10 to 20 km may be installed every two to three years.

Cable Manufacturing

Copenhagen Energy purchases cables from several manufacturers in Europe, one of which is NKT. NKT has manufactured more than 20 circuit km of 420 kV XLPE for Copenhagen Energy and has received an order to manufacture another 12 circuit km of this type of cable, to be installed in Copenhagen by August of 1999. NKT is manufacturing the cable on a catenary extruder and the conductor is a 1,600 mm^2 copper with a solid aluminum conductor center. The conductor design is a modified Conci design with four layers of key-stone shaped copper strips wound over a solid aluminum core. The overall conductor diameter is about two inches, and the diameter over the cable jacket is about 5.5 inches. NKT has also supplied 145 kV XLPE cable constructions to Copenhagen Energy.

Permit Process

The permitting process in Denmark involves both the federal and local governments. Usually the utility will submit a plan to the authorities and the review process will take one to three years. For an overhead line, if applicable, the process may take as long as ten years. As an example of the local population influence, the Kontek 400 kV DC circuit was proposed as an overhead line in Denmark to a point where it is changed to a submarine cable across the Baltic Sea to Rostock, Germany. Because of opposition from the land owners along the proposed overhead route, the total circuit length in Denmark was installed as an underground cable a distance of about 110 km.

The 420 kV transmission cable loop around Copenhagen will be replacing several existing overhead circuits that would have required upgrading to serve future load requirements. The utility decided to install the underground transmission cable circuits to avoid delays in getting the load capacity in place when it was needed.

Design of Cable

A proposed cable circuit will be evaluated from a design load carrying criteria, and the appropriate conductor size selected within the standards established by the utility.

Two standard conductor sizes are used for the paper insulated cable, a 240 mm^2 and an 800 mm^2 copper conductor. For the 145 kV XLPE cable type, the conductor sizes are 800 mm^2 and 1,600 mm^2 aluminum. The installation modes are a triangular configuration for the 800 mm^2 and a flat formation for the 1,600 mm^2. Depending on the circuit lengths, the sheath bonding will be cross-bonded, center point grounded, or single point grounded at one termination. Some of the cable constructions employ a lead sheath designed for a short circuit current of 40 kA for one second. Other constructions include concentric copper wires under a laminated aluminum sheath. The design requirement for the copper wire cross-section area is 200 mm^2 to carry the 40 kA short circuit current.

Installation Methods

The normal installation mode is direct buried, both in city streets and in rural areas. The progression rate for digging the trench in the city can be as slow as eight meters per day. In a rural environment, such as when the 400 kV DC Kontek cable was installed, it can be as much as 200 meters per hour.

In the city the trench will be constructed with shoring of the sides. A concrete bottom will be poured, and the cables will be pulled into the trench. Often, a total of two km of cable trench will be completed before the cables are pulled in, which in city environments may require the first section of trench to stay open for more than a month. The cable sections being pulled into the open trench range from 700 to 1,000 meters, with sections up to 1,600 meters being the exception. For the 420 kV XLPE circuits, the maximum cable length on a reel was 870 meters.

During the installation of the Kontek cable, a machine would scrape off the top soil and place it on one side of the trench. A backhoe was equipped with a shovel designed with the same shape as the trench and large enough to remove enough soil in one operation. Rollers were placed in the trench and the cable was then pulled in. The trench was back-filled with the existing soil and the top soil placed over of the trench so farmers could start planting. As a “protection” of the cables, warning tapes were placed about 10 inches above the cables prior to completing the back-filling of the trench.

During the installation of the 145 kV XLPE cable circuit through Copenhagen, the trench construction was limited to off-traffic peak hours, with work being done evenings, Saturdays and Sundays. A typical trench that could stay open for more than one month is shown in Figure 7-1. All of the figures in this section are courtesy of Copenhagen Energy.

Figure 7-1
Typical Open Trench Barriers in Copenhagen

The reel transport to the site is performed on a special carrier designed to hold reels up to almost 5 meters in diameter. The hydraulic design of the carrier is such that during transport, the reel can be lowered to a few centimeters over the road surface. This will allow the five meter reel to pass under a bridge of a height of a few centimeters more than five meters. This allows for getting long lengths of cables to locations that otherwise would not be passable.

Depending on the trench layout, “Cable Dogs,” which are electric operated pushers, are installed in the trench on the cable to help push the cable along in the trench. Up to four pushers can be used during the installation of one cable length. Figure 7-2 shows a pusher installed in the trench with the pulling rope installed.

Figure 7-2
“Cable Dog”

In some instances, it is possible to set up a construction train as shown in Figure 7-3. Here the front end is the backhoe that digs the trench and loads the spoils onto dump trucks. Then relatively quick-set concrete, about 20 cm (8 inches) is poured into the bottom of the trench. The rollers and pushers are placed in the trench and the cable is pulled into the trench. After all the cable phases are pulled in, a layer if “weakmix,” which is weak concrete slurry, is poured over the cables in a layer of about 25 cm (10 inches). About 80 cm (31 inches) of soil is placed in the trench on top of which another layer of about 35 cm (14 inches) of concrete is poured. The trench is finished off with the specified road material. Often, two circuits in flat configuration will be installed in the same trench. In some installations, the center phase will have a fiber optic cable tied to it. The fiber optic cable will be used for temperature monitoring and communication. The spoil from the trench is used as the backfill. Usually, the thermal characteristics of the combination of the concrete and the spoil are satisfactory for operating the cable circuits at their design limits. The cable reel carriers and the cable pushers are owned by the utilities. With several utilities in Denmark installing transmission cables, the equipment is being leased among all of the companies.

Figure 7-3
Construction Train

Contractors, with the splices and terminations being installed by the manufacturer will do the excavating and pulling in the cables. During all installation phases of a cable project, the utility will have qualified inspectors at the job site at all times following the project.

Directional drilling is used crossing road intersections not to interfere wit the traffic at those locations. Figures 7-4 and 7-5 show two such directional drillings in an 870 meter (2,850 feet) long 420 kV 1,600 mm^2 (3,160 kcmil) copper conductor with solid aluminum center. The length of the directional drilled sections range from 50 to 150 meters (165 to 500 feet).

In areas of known contaminated soils, directional drilling will be performed. The amount of contaminated spoil that needs to be discarded will be substantially decreased compared to the conventional open trench installation method.

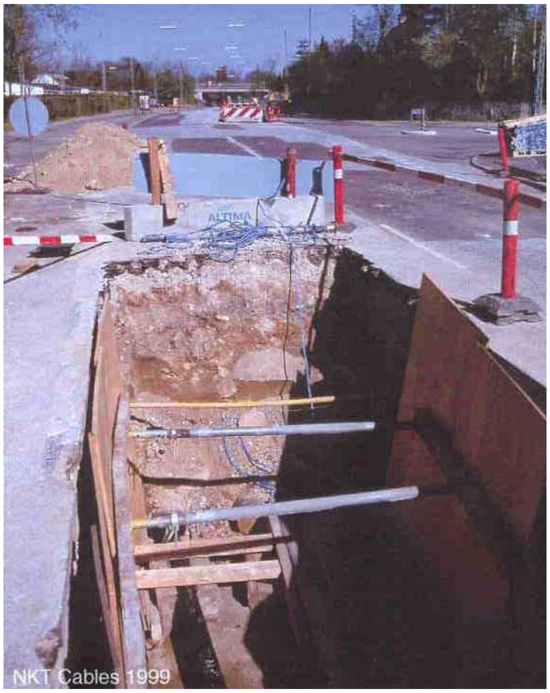


Figure 7-4
Directional Drilling

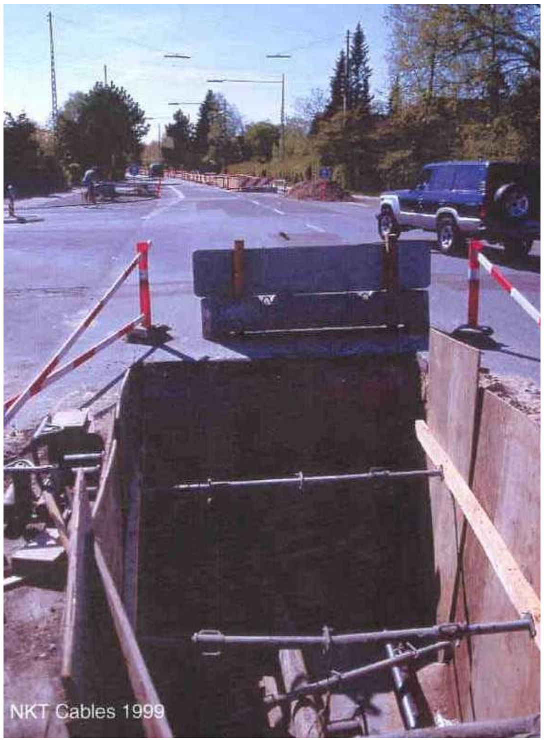


Figure 7-5
Directional Drilling

US Applicability

Of possible special interest to the US transmission cable user are:

- Special cable reel trailer which can accommodate longer cable lengths and use roads with lower bridges
- Use of specific designed excavation equipment for trenching (similar to what was used during installation of the Kontek cable)
- Use of Cable Dogs to increase the cable pulling lengths
- Use of construction train

Switzerland

Brugg Cable was visited on May 6 and 7 and is one of the leading transmission cable manufacturers in Switzerland. The meetings were held at their XLPE cable and accessories manufacturing facilities in Brugg, Switzerland. The transmission voltages in Switzerland are 400 kV, 245 kV, 170 kV, 145 kV, 123 kV, and 60 kV. At 400 kV, all the circuits are overhead lines. The cable types used for 245 kV are SCFF (70%) and XLPE (30%), at 170, 145, and 123 kV the insulation is XLPE (90%) and EPR (10%), and at 60 kV XLPE and EPR are used in about equal amount. There are about 40 circuit km of 245 kV cable installed, 175 km at 170 kV, 180 km at 145 kV, and 120 km at 123 kV. The 60 kV circuit km was not available. Most new cable circuits being installed use extruded insulation. The data presented above is based on discussions with Brugg Cable personnel and also from a 1994 Cigre publication[3].

Cable Manufacturing

The Brugg XLPE transmission cables are manufactured on the "Long Land Die" equipment. All constructions are now being manufactured with an extruded semiconducting insulation shield using the industry standard of 1 to 2 mm thickness. This is used rather than the very thin semiconducting insulation shield that was used previously on cables manufactured on this type of equipment. The factory is located on a relatively small plot of land so the layout is very compact but efficient.

The accessories fabricating facility includes its own test area and 100% of the accessories are tested prior to being shipped. Research and testing were in progress for improved SF_6 terminations. These new designs will make the field installation simpler and possibly lower the installed cost of a cable circuit.

[3] "HV Cable Networks in Switzerland – Particularities and Experience" R. Bautz, et. al., CIGRE 1994 Session, Paris, France, 28 August – 3 September, 1994

Permit Process

There are 26 utility companies in Switzerland, and about 25% of them are publicly owned with the rest being owned by the federal and local governments. The permit process is very much controlled by the federal and local authorities. The utility will justify what additional transmission capacity is required and public hearings will be conducted. Based on the results of these hearings, the utility will prepare the final documents for approval by the federal agencies. The average time to receive a permit for an underground transmission cable circuit is about one year. For overhead circuits it can be as long as ten years. One specific situation was noted where the permit process extended over 20 years, and was finally approved as an overhead circuit. The utilities work closely with the cable manufacturers during the permitting process to assure that the proposed transmission circuit can be manufactured and installed within the established budget.

Design of Cable

All transmission cables installed in Switzerland employ a metallic moisture barrier of corrugated copper or aluminum, or use a copper or aluminum laminate tape. Lead is considered a hazardous material in Switzerland. The most common conductor size is an 800 mm^2 solid aluminum conductor. Usually, a moisture absorbent tape will be placed over the extruded semiconducting insulation shield.

Installation Methods

Since about 1975, 80 to 90% of the transmission cable circuits in Switzerland have been installed in a polyethylene duct imbedded in concrete. In congested areas, a tunnel may be constructed about 10 meters below the surface. The cables will be installed on the tunnel wall using special hangers and supports that allow the cable to move during the normal load cycling.

Several installations were directional drilled, when known contaminated soils were present on the proposed cable route. Brugg had a subsidiary specifically devoted to directional drilling, but it was sold to an independent contractor.

US Applicability

Some of the items that are applicable to the US transmission cable users are:

- Develop an Installation Partnership between the transmission cable owner, cable manufacturer
- Use of directional drilling at know contaminated sites

France

Electricit— de France (EDF) was visited at their Site des Renardi—res research center in Moret-sur-Loing, about 80 km south of Paris. At this facility all new and improved transmission cable types and their accessories are long-term tested. Tests are also performed here for cable and accessory manufacturers. The voltage classes used in France are 20 kV, 63 kV, 90 kV, 225 kV, and 400 kV. A total of 2,700 circuit km of 63 kV rated cable and 1,785 circuit km of 90 kV rated cables are installed on the EDF system. EDF has a total of 830 circuit km of 225 kV cable and 26 circuit km of 400 kV cable.

Between 10 and 50 circuit km of transmission cable is installed yearly in France. For 63 to 90 kV the cost of undergrounding is about three times as expensive as overhead lines. At 225 kV the cost is ten times the overhead line cost and for 400 kV cable circuits, the cost is 15 to 20 times as much as the cost of an overhead circuit.

Electric and Magnetic Fields (EMF) is not an issue for cable circuits, but it is for overhead lines. Cross-bonding is used infrequently since usually the cable circuit length is relatively short. The maximum allowable sheath voltage is 200 volts during normal operation.

Cable Manufacturing

EDF has three approved suppliers of transmission cables, all having manufacturing facilities in France. With the Common Market being implemented, more manufacturers may be approved by EDF. It is known that one manufacturer uses a vertical extruder for the high voltage XLPE cables. Several extruded dielectric cables are installed on the French system, including low-density polyethylene (LDPE), high-density polyethylene (HDPE), and cross-linked polyethylene (XLPE). EDF now specifies XLPE insulation for all cables installed at and above 225 kV.

Permit Process

The permit process requires justification for new circuits and approval by both the local and federal governments. The approval process for cable circuits is about one year.

Design of Cable

The conductor material is aluminum or copper for sizes 630 mm^2 and 1,200 mm^2 and copper for 1,600 mm2. The 650 mm^2 conductors are stranded and the larger sizes are Milliken type. The maximum electrical design stress is 10 kV/mm for 220 kV and above, following the proposed IEC requirements. The normal design conductor temperature is 70°C for low density polyethylene and 80°C for high density polyethylene. XLPE design temperature is 90°C conductor temperature. The 225 kV cables have a lead sheath and PVC or polyethylene jacket. A construction with a laminate metallic moisture barrier under test has passed the qualification requirements. One 400 kV cable design has aluminum wires and lead sheath designed to carry 63 kA short-circuit current for 0.5 second. Another construction has aluminum wires and a laminate aluminum tape also designed for 63 kA short-circuit current for 0.5 second. The jacket for both designs is extruded polyethylene.

Installation Methods

Cables up to 90 kV will be direct buried if that is at all feasible. The cable configuration can either be in flat formation or in triangular configuration. The splices will also be direct buried. An “Installation Train” is often used where the cables are installed in direct burial configuration. The trench is dug or “cut” with the spoil laid on one side of the trench. The three cable drums are installed on a reel carrier that is located in front of the train. As the trench is prepared, the cables are lowered into the trench on a tray that allows the cables to be vibrated as the weak concrete mix backfill is poured over the cables in such a manner that the cables will be laying on a layer of concrete. Figure 7-6 is from a Jicable 95 paper[4] presented by EDF.

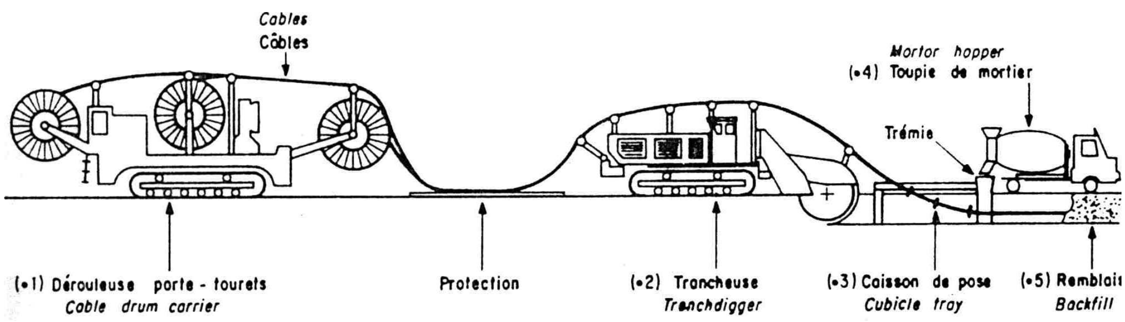


Figure 7-6
Cable Laying Train used by EDF

Installation in PVC ducts or installation in troughs either in trefoil or in flat formation is done for the 225 and 400 kV circuits. Installation in tunnels are also used.

Contractors approved by EDF do the installation of transmission cables. There are about five contractors approved for the installation of the 225 and 40 kV underground cables.

US Applicability

Some of the items that are applicable to the US transmission cable users are:

- Use of construction train.
- Use of vibrator during the installation of thermal backfill around cables installed in tri-foil configuration.

The Netherlands

NK Cables, the merged NKF Cables of the Netherlands and Nokia Cable of Finland, was visited at their facilities in Delft, the Netherlands. XLPE cable and accessories are manufactured and tested at this facility. XLPE transmission cables are also being manufactured in Finland at the former Nokia manufacturing facilities.

[4] “Mechanized Laying of HV Cables,” P. Durand, S Le Peurian, Jicable 95, paper A.2.1.

Cable Manufacturing

In Finland the XLPE cables are manufactured using vertical extrusion technology. In the Netherlands, the cables are produced using the Long Land Die technology.

Permit Process

All transmission circuits up through 170 kV are by law required to be installed underground. The permitting process still requires the utility to present the justification for the circuit to federal and local governments. The approval process can usually be completed within one year.

Design of Cable

The XLPE cable is always designed with metallic moisture barriers, which can be a lead sheath or a metallic laminate. The conductor is often a solid aluminum conductor up to 1,200 mm^2. It is common to install a fiber optic wire together with the concentric wires around the cable when a laminate sheath is used. Otherwise it is installed under the lead sheath and in both cases the fiber optic wire is used for temperature monitoring. A polyethylene jacket is extruded over the metallic moisture barrier.

Research has been done in the Netherlands showing that it may take as long as 115 years for moisture to penetrate certain types of polyethylene jackets in combination with swelling tape[5]. It was not clear if the utilities in the Netherlands are planning to install transmission cables of this construction.

Installation Methods

Almost all of the transmission cables are installed direct buried. All splices are also installed direct buried. Therefore, the method of preparing the cable ends for acceptance of the pre-fabricated splice becomes a very attractive way of installing the splices. The section length is not critical since the adjustment of the overall cable circuit length will be done at the ends of the cable circuit when the terminations are installed.

Directional drilling is often done at road and canal crossings. It is also used where known soil contamination exists in order to minimize the spoil removed from the construction site.

Accessory designs are currently being developed which incorporate monitoring methods for splices and terminations. A design for use with a concentric wire shield is described in a paper presented at the August 1998 CIGRE[6] meeting. Methods for use with lead sheath constructions are also available.

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[5] W.S.M. Geurts, E.F. Steennis, C.J.H.M. Poorts, G.J. Meijer. “Water Diffusion through Sheaths and Its Effect on Cable Construction.” Jicable 95, paper f.3.

[6] “Development and Qualification of a new 400 kV XLPE Cable System with Integrated Sensor for Diagnostics,” G.P. Van Der Wijk, E. Pultrum, H.T.F. Geene. CIGRE paper 21-103, Session 1998.

Several designs of SF_6 terminations and slip-on, pre-molded splices and terminations are being tested and installed. These designs will allow factory preparation of the cables for both the terminations and splices.

US Applicability

The items that are applicable to the US installation methods include:

- Prefabricated cable ends for terminations and splices
- Directional drilling on a routine basis at water and road crossings
- Direct burial of splices

Recommendations

The new products being developed in Europe may affect the installed cost of transmission cable circuits in the US if they are proven to be technically compatible with the US industry standards. EPRI members could benefit from a program that will certify these new products to the applicable specifications and standards. The certification could be done either at US or European test facilities, depending on where the most efficient and cost effective testing can be performed.

A tailored collaboration project incorporating these products could be the next step to prove both the technical and economical benefits from these products.

Some of the cable delivery and installation methods should be investigated for use in the US. For example, large reel carriers may allow installation of longer section lengths improving the reliability by reducing the number of splices. Modifying open-trench restrictions may improve the time required for installing a cable, which will lower the installed cost of transmission cable circuits. Use of directional drilling options could result in shorter installation time in congested city road intersections. The utilities would benefit from working with local authorities to update and improve local ordinances dealing with trenching and drilling in city streets.

8
STANDARDIZATION VERSUS CUSTOM DESIGN

Introduction

Historically, underground transmission cables have been custom designed, on almost a foot-by-foot basis, because of the high unit cost, the infrequency of transmission cable installation – and partially because utilities had the resources to perform such analysis. Today, more circuits are being installed by utilities that do not have staff devoted to underground transmission, and costs can perhaps be lowered by standardizing on design and installation.

Standardization can have significant benefit to a utility that installs a large amount of cable. For those utilities that have infrequent transmission cable applications, standardization will not be an issue.

Integration into Analysis Matrix

A standardized analysis procedure has been developed for more than three dozen items that can be considered to reduce cable system cost. Standardization affects every analysis area: Planning, Permitting and Routing, Cable System Design, Engineering, Civil Design, Materials, Machines, Installation, and the Business Case. A summary taken from the Analysis Matrix is given on the next page, and examples of detailed analysis are provided on the following pages.

Table 8-1
Standardization Analysis Summary by Evaluation Area

Area	Affected Parameter	Project Adjustment	Cost Effect
Planning	Standardized ratings. Affects power flow. May not provide for future expansion	Accept higher ratings than optimal. Worry about having ratings that are too low, reducing cable life	Higher or lower, depending upon project
Cable System Design	Engineering design: Ampacity analysis, Etc.	Reduce amount of engineering by utility and by manufacturer	Reduce costs
Permitting, Routing	Standardized design will have less questions from permitting authorities	Simplify, since cable design does not have to be performed for each route	Reduce cost; shorten time
Engineering (A-E type work)	Manpower required for detailed design drawings, specs	Greatly simplify.	Reduce costs
Civil Design	Specifications, contractors	Prepare generic standards, less need for high-level supervision	Reduce costs
Materials	Design, procurement, spare parts	Perform cable design once; obtain benefits in procurement (bulk orders?), reduce spare parts	Reduce costs
Machines	No anticipated effect		
Installation	Specifications, contractors	General specifications not needed for each job. Term contracts for contractors	Reduce costs
Business Case	Don’t sweat the details on every job		Reduce cost

Applicable Routes

Standardization should definitely apply to suburban and rural routes. For urban areas, it may be possible to standardize on a cable size and construction. However, engineering details such as ampacity, pulling lengths, sheath voltages, etc. will probably have to be analyzed since installation conditions can vary so widely in urban areas.

Issues

Just as for distribution cable system, the utility will develop a Standard, which is the basis for all transmission cable extruded-dielectric installations. This Standard will specify only a few cable sizes (perhaps “high power” and “low power”) and the utility will not accept other cable sizes without compelling reason.

A standard installation specification will be prepared. Since the utility will not devote significant engineering time to individual projects, a great deal of latitude will be given to field staff to make detailed decisions within the framework of the standard.

In discussions with manufacturers and major cable-using utilities, it appears unlikely that individual utilities can place an order large enough to provide bulk-quantity prices for transmission cables. However, it may be feasible to combine the transmission cable term order with that for distribution cables. Even though the manufacturer may not have the economy of scale enjoyed for distribution cables, he will have an incentive to keep the price for the transmission cable low.

Standardizing will reduce the spare parts inventory for the utility, and should provide a modest improvement in restoration time after an outage.

Standardizing on cable construction and installation methods should allow the utility to standardize on installation equipment. This may not be an issue if installation is typically performed by contractors, but it can be important if the utility performs its own cable installation.

Transition structures are not a major item in total cable system cost (except for very short cable lines) but they can have significant impact on project time schedule – which has an effect on cost. A standardized design will reduce material costs somewhat, and will reduce overall costs in cases where the structure is the critical path item.

Ampacity

Since detailed ampacity calculations will not be performed for each new circuit, the utility should perform a general ampacity analysis that will cover all installation and operating conditions, and select a cable that will meet a the maximum ampacity requirements for typical installations – recognizing that there may be special installations that have significantly different requirements. The cable may be oversized for many applications – reducing cost of losses and increasing life. Selecting a “low power” and “high power” cable will help insure that cables are not grossly oversized – and that they are not undersized.

Cost Implications

The goal of standardization is to reduce overall cost, by economy of scale and by eliminating most of the detailed engineering and design. It is difficult to quantify the effects without actually applying standardization to a utility, or group of utilities, that installs a large amount of cable. As a first cut, we developed approximate costs for our “typical” circuit, which is a single 750-kcmil aluminum-conductor circuit, installed in a 2 x 2 ductbank.

We made reasonable 5 – 10% reductions in material and installation costs, and much larger reductions of 50% in permitting and engineering design. We assumed that the project required a 750-kcmil aluminum cable rated 610 amperes for the Conventional installation. For the Standard installation, we assumed the utility standardized on a 1000 kcmil cable which is rated at 706 amperes, but is carrying 610 amperes. We calculated the savings in the 40-year cost of losses ($1000/kW demand charge, $0.05/kWhr energy charge with no escalation) for both approaches. The cost summary is given below. Note that these numbers are generic; any specific project may have significantly different costs for any of the listed categories.

Table 8-2
Estimated Costs, Thousand Dollars

Item	Conventional	Standardized
Cable, splices, duct, manholes, link boxes, etc.	$1,950	$1,995
Civil works (trenching, spoil disposal, concrete envelope, backfill, paving, etc.)	$790	$765
Terminations, transition pole, arresters, etc.	$465	$440
Permitting, surveying, engineering, construction supervision, performance bond, mobilize, demob, staging, commissioning	$465	$300
Subtotal, without Cost of Losses	$3,670	$3,500
Cost of demand, plus 40-year energy losses	$707	$497
TOTAL	$4,377	$3,997

Using these figures, the savings would be about 5% neglecting the cost of losses. The savings would be greater, except for using the more costly, larger-conductor cable. The utility would obtain a 9% cost savings using the standardized design, taking into account the cost of losses at the fairly low rates assumed for this example. (In the new competitive market, it is unclear who would pay the cost of losses – and therefore who would benefit from the savings. . . .)