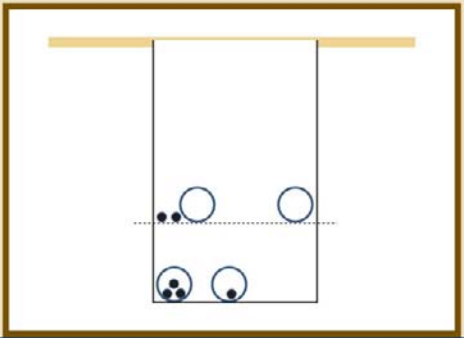
ASCE Manuals and Reports on Engineering Practice No. 118

Belowground Pipeline Networks for Utility Cables



ASCE

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Belowground Pipeline Networks for Utility Cables

Prepared by
the Pipeline Planning and Design Committee and
the Underground Pipeline Asset Management Committee of
the Pipeline Division of
the American Society of Civil Engineers

Edited by
Lawrence M. Slavin, Ph.D.

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PREFACE

This manual was prepared by the Task Committee on Belowground Pipeline Networks for Utility Cables of the ASCE Pipeline Planning and Design Committee and of the ASCE Underground Pipeline Asset Management Committee, in a cooperative effort, under supervision of the Pipeline Division. The manual provides a general overview of methods for placing utility cables belowground, including formal underground conduit systems and relatively low-cost direct-buried facilities, with emphasis on a belowground cable network that represents a cost-effective and space-efficient installation. The Pipeline Planning and Design Committee, under the leadership of Chairman Sam A. Arnaout, in cooperation with the Underground Pipeline Asset Management Committee, under the leadership of Chairman Thomas D. Iseley, are responsible for the efforts leading to this publication. The committees would like to thank contributors, task committee members, and reviewers, whose names follow, for their support, time, and effort. The Task Committee chairmen greatly appreciate the support and guidance provided by the U.S. Department of Transportation and the FHWA Turner–Fairbank Highway Research Center.

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ASCE Belowground Pipeline Networks for Utility Cables

ACKNOWLEDGMENTS

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INTRODUCTION

1.1 SCOPE

Underground pipes, or conduits, represent a routine means of installing and protecting cables, including telephone, cable television (CATV), and electric power supply lines. An array of such pipes, often encased in concrete, is typically part of a formal conduit network, including manholes placed at access points along the route, and is commonly used in urban areas and other locations for which the periodic placement of such cables is planned or anticipated. In contrast, the use of individual pipes or ducts placed in a trench, similar to direct-buried[1] cables is less common, but has occasionally been used by individual utilities to provide a degree of upgrade capability not otherwise provided by conventional, low-cost, direct-buried construction methods. Such applications have not been used on a routine or coordinated basis among the utilities, although such utility companies may be sharing a single, joint-use trench. In the present context, *joint-use* refers to the sharing of aboveground or belowground facilities by several utilities or organizations using cables, such as electric power and communication (telephone or CATV) companies.

The objective of this book is to present a brief description of present and past practices for the placement of utility cables belowground, including conventional underground conduit systems and direct-buried methods, as well as more recent techniques in which individual pipes or ducts may be advantageously deployed in conjunction with direct-buried cables. Related design, construction, and operational requirements and

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[1] See the Glossary for the definition of terms used throughout this book.

guidelines are also provided. Finally, specific design and implementation information is provided for a cost-effective, space efficient hybrid joint-use system for utility cables that provides many advantages relative to previous or existing methods of belowground construction. In general, however, it is not the intention of this book to provide or duplicate existing detailed design, construction, or installation specifications and information as currently used by the various utilities for their belowground cable facilities. Such information is available within the individual utilities or their representative organizations. Although much of the information in this book is applicable to a variety of applications, some of the information tends to be more appropriate for specific portions of the power and communication networks, e.g., the local distribution system toward the customer end of the network.

The book is divided into six chapters. This chapter includes a description of the general categories of construction methods relevant to utility cables. Chapter 2 provides a description of underground conduit systems, including an overview of installation, operation, and maintenance procedures. Chapter 3 provides analogous information for direct-buried systems, including the limited use of pipes or ducts. A description of various methods for installing cables within ducts is contained in Chapter 4, which also includes an explanation of basic engineering principles governing such installations. Chapter 5 presents a detailed description of a particular example of a belowground cable network (BCN), including related planning, design, maintenance, and management rules for this hybrid system, which combines the advantages of direct-buried and underground conduit construction methods. Chapter 6 reviews the status of the described BCN, including the results of recent field applications and anticipated future introduction into industrial applications. A glossary of terms and a list of references are provided at the end of the book. This manual is useful for new and experienced engineers alike in road and community construction, as well as utility owners, contractors, municipalities, other project owners, and other industry professionals. It provides both introductory and specific design and construction information to support the implementation of the proposed hybrid belowground cable network.

1.2 BACKGROUND

There are basically three modes of construction for outside plant facilities for communication and electric power supply lines. These are the following:

1. aerial or overhead plant in which the cables are individually suspended between utility poles placed on the order of 100 to 300 ft apart,

2. belowground plant, consisting of an array of parallel conduit paths, typically 4- to 6-in.-diameter pipe, spanning the distance between relatively large manholes, separated by distances on the order of 500 to 1,000 ft, and
3. belowground plant installed by directly burying the cables within the soil, including cables along a road or highway and service drops to the home.

Because of the significantly different characteristics of the two belowground methods, mode 2 has been specifically designated as "underground (conduit) plant" to distinguish it from mode 3, which uses individual "direct-buried" cables. Unfortunately, this terminology has not been universally adapted outside of the communication and power industry, where the terms "underground" or "buried" may be used interchangeably, to refer to mode 2 or mode 3. (In this book, the type of belowground construction described is clear from the context.)

Figure 1-1 illustrates a typical distribution utility pole application, including sharing or joint usage, of the pole for supporting electric power supply and communication lines.

Figure 1-2 illustrates typical belowground (i.e., underground conduit and direct-buried) construction alternatives.

All three modes have been commonly used in the industry, with an increasing amount of belowground facilities being placed relative to aerial plant in more recent decades, primarily driven by regulations. For example, the large majority of new construction in local (residential) subdivisions deploys direct-buried facilities, and communities and various levels of government are also demanding a greater portion of belowground construction along roads and thoroughfares, primarily because of

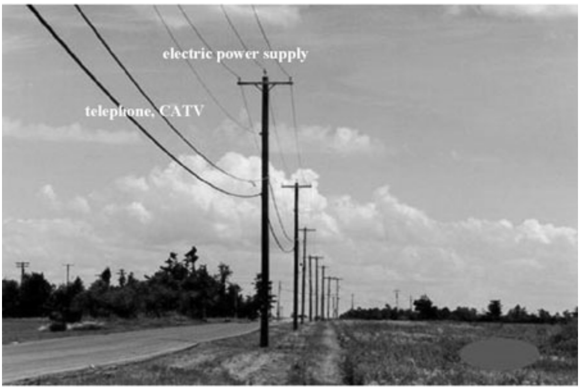
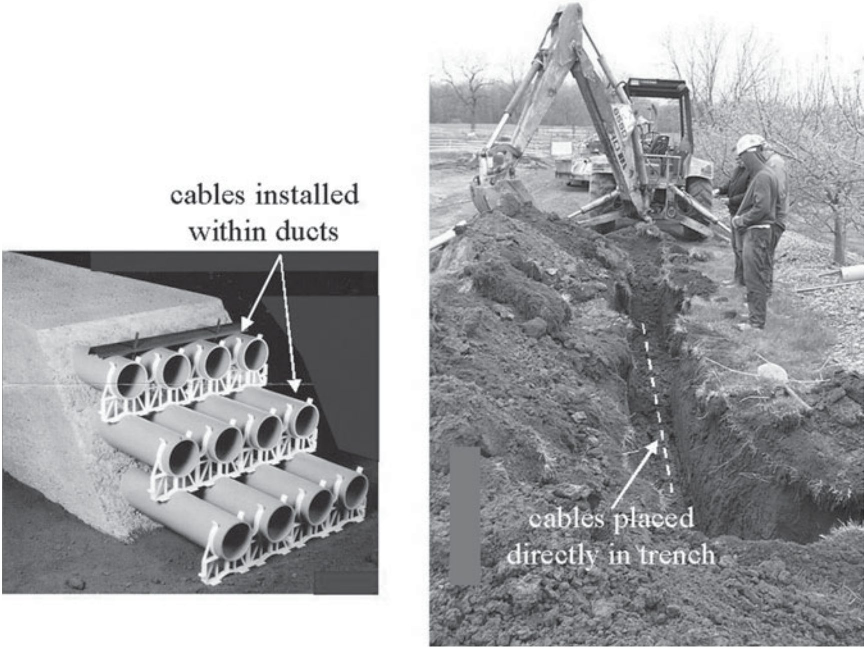


Figure 1-1. Typical Joint-Use Utility Pole Application.



a b

Figure 1-2. Typical Belowground Construction. (a) Underground Conduit (Courtesy of Underground Devices) and (b) Direct-Buried.

aesthetic and safety considerations. Utility pole collisions account for a significant fraction of automotive fatalities along the nation's roads and highways. The extensive conduit facilities of underground plant (mode 2) are appropriate for limited applications, such as those associated with the trunk or feeder portions of the traditional telecommunication network, because of the high cost of this method of construction. The construction of the conduit networks is material- and labor-intensive and requires significant manhole real estate, but it does provide flexibility, including the capability to postpone installation of expensive trunk or feeder facilities (e.g., for fiber-optic cables) until the need arises. Such underground conduit systems are also the only viable alternative in metropolitan or large urban areas, where overhead lines and future digging are not options.

In contrast, direct-buried plant (mode 3) represents a relatively low-cost method for placing individual cables belowground between any desired terminations, but the method loses flexibility with respect to future additions or replacements. Indeed, the inherent lack of such upgradability has been a primary factor in inhibiting the desired widespread deployment of new wireline telecommunication technologies, based on the use of fiber-optic cables, in established areas and communities with buried facilities. (Newly constructed areas using direct-buried construction temporarily escape this problem, only to face it in the future, when still newer technologies are desired or maintenance is necessary.) Conversely, existing communities served by aerial distribution plant (mode 1) have been ready candidates for such upgrades. Similarly, energy-hungry consumers and industries continue to push the limit of existing power lines that need to be replaced or supplemented. Thus, in addition to the relatively low cost to install and maintain aerial facilities, flexibility represents another reason for the continuing deployment of aerial lines.

The increasing deployment of wireless technologies (e.g., cellular phones and satellite TV) has greatly affected the communication industry, resulting in lost revenue for some of the wireline-based utilities. Nonetheless, it will be a long time, if ever, before cable-based wireline communications become replaced and discarded. Wireless technology is inherently inferior to wireline (e.g., copper, fiber, or coaxial) technologies with respect to various characteristics and features (e.g., security, reliability, quality, information capacity, and possible independence from batteries or commercial power), thereby inhibiting elimination of physical cables. The present major investment in new wireline facilities by the major telephone companies, wherever feasible, bears witness to this principle. Furthermore, “wireless” systems often contain wireline portions for various segments, such as for interconnecting towers and cell sites. Although various alternatives are being pursued for new, renewable energy sources for electric power, the use of physical cables for providing electric power supply to homes and industries will be required for the indefinite future.

The current trends for buried construction across much of the country introduce potentially serious problems when upgrades and maintenance are inevitably required in the future. In such cases, digging in established areas is typically required, often accompanied by damage to public and private property, including roads, and associated traffic problems. Furthermore, safety problems arise when digging in an area with existing utilities. Even when proper procedures (e.g., one-call notification, identification, utility location, and manual exposure) are followed, accidents can occur, resulting in property damage, personal injury, and possibly death. The use of trenchless technology, including horizontal directional drilling (HDD), following proper procedures, reduces the degree and likelihood of such problems but does not eliminate them and typically has a significant cost penalty. Thus, although current trends in the widespread use of buried construction are desirable, there is an urgent need to modify present construction practices to avoid unfortunate future problems, including significant safety issues. Chapter 5 of this manual provides specific design and implementation rules for a hybrid, cost-effective, space-efficient joint-trenching system for utility cables combining the advantages of direct-buried and underground conduit construction methods.

Current practices for the placement of communication and power supply lines and the shared usage of facilities (e.g., poles, underground conduit systems, and trenches), for all three modes of construction are supported by utility industry standards and documents, including the National Electrical Safety Code (IEEE 2007) and the Telcordia *Blue Book—Manual of Construction Procedures* for the telephone industry (Telcordia 2007). Such practices are also encouraged by transportation authorities, including the Federal Highway Administration (FHWA 1993) and the American Association of State Highway and Transportation Officials (AASHTO 2005). Transportation corridors directly benefit by such efficient usage of the valuable right-of-way space alongside roads and highways, as well as from reduced damage to the environment, improved aesthetics, and possible improved safety for vehicular traffic.

2

UNDERGROUND CONDUIT SYSTEMS

2.1 GENERAL

A typical underground conduit system is made of an array of ducts at fixed horizontal and vertical spacing, spanning distances of hundreds of feet or more, between which they are terminated in manholes or other belowground structures. The ducts may be constructed of a wide variety of materials—in the past, including clay, concrete, or fiber-cement, with more modern systems including various types of plastic products. This book does not provide a detailed list of all types of supplier products that may be used as part of an underground conduit system. Such information is readily available from pipe vendors and other manufacturers. Briefly, however, plastic products are currently the dominant product in the market for cable conduit applications. Polyvinyl chloride (PVC) is the most common type of duct used, but high-density polyethylene (HDPE) is also widely used. Duct sizes of 4- to 6-in. diameter are commonly used. In most cases, the installed ducts are placed in a trench (Figs. 2-1 and 2-2), following recommended practices for trench preparation and backfill, possibly encased or capped in concrete for additional protection, as indicated in Fig. 1-2(a). Additional information is provided in Section 2.2.

The conduits are terminated at underground structures, typically belowground manholes or vaults, within which utility equipment, splices, or both may be located (Fig. 2-3). Common manholes are not waterproof and may collect water and possibly undesirable gases; proper procedures must be followed on entering such structures. In some cases, controlled environment vaults are used to contain sensitive equipment and hardware (Telcordia 1994). Although both communication and electric power

Figure 2-1. Underground PVC Conduit System (Courtesy of Prime Conduit).

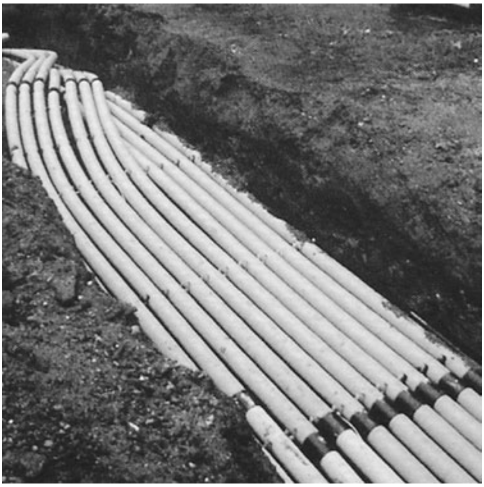


Figure 2-2. Underground HDPE Conduit System (Courtesy of A-D Technologies).

supply cables and equipment may be safely contained within the same structure (IEEE 2007), common practices often deliberately avoid this option. Thus, the bank of conduits within a trench may contain both types of cables,[1] but the conduits serving communication facilities would often terminate in separate manholes than those serving electric power.

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[1] Communication and power cables must be placed within separate conduits unless they are operated and maintained by the same utility.

Figure 2-3. Telephone Vault (Courtesy of Oldcastle Precast).

Figure 2-4. Polymer Concrete Handholes (Courtesy of Quazite, Hubbell Power Systems, Lenoir City).

Underground conduit systems may also include other components in addition to the basic array of conduits and typical manholes or vaults suitable for man-entry and access. Smaller structures, such as handholes (Fig. 2-4), may conveniently be provided in the network for local access to individual ducts or to contain hardware.

2.2 DESIGN AND CONSTRUCTION REQUIREMENTS

Underground conduit systems have been in common use for many years, and extensive practices and procedures have evolved to help ensure their efficient and safe design and use. Such practices have been provided by the communication and power utilities, as well as suppliers of associated products. The basis for many of the current procedures is the original set of Bell System Practices, primarily developed within the telecommunication industry under the auspices of the original American Telephone & Telegraph Company (AT&T). A particularly important document is the *National Electrical Safety Code* (NESC), published by the Institute of Electrical and Electronics Engineers (IEEE 2007). The NESC is reissued every five years and contains safety requirements for the wireline communication and power supply industries within the United States, as applicable to outdoor facilities under the control of the utilities. The NESC—typically the most recent edition, but sometimes an earlier issue—is adopted as a requirement imposed on the utilities by the public service commissions in most states.

2.2.1 Safety-Based Requirements

The NESC is intended to provide basic safety rules for the communication and power supply utilities, but it is not intended to be a design document. Nonetheless, many of the requirements directly or indirectly affect the design and construction, as well as the use, of underground conduit systems. Although Chapter 1 of this manual suggests that there is a clear distinction between the mode 2 (underground conduit system) and mode 3 (direct-buried cables) methods of construction, in practice there have been variations in each category that tend to blur the differences. The NESC attempts to define the two categories as follows [*emphasis added*]:

> While it is often the practice to use duct and conduit interchangeably, *duct,* as used herein, is a single enclosed raceway for conductors or cable; *conduit* is a structure containing one or more ducts; and *conduit system* is the combination of conduit, conduits, manholes, handholes, and/or vaults joined to form an integrated whole.

The NESC adds, "For cables installed in a *single duct* not part of a conduit system," the rules for *direct-buried cable* apply.

The rules for each category are provided within separate sections of the NESC document. It is not difficult, however, to imagine that there are cases in which the construction details may not clearly fall within either category, and some judgment is required to determine which rules are applicable. Whereas the NESC attempts to distinguish between the terms "duct" and "conduit" for its purposes in providing safety rules for the two general modes of belowground construction, this manual uses these terms, as well as "pipe," interchangeably, with the intent clear from the context.

The safety rules regarding underground conduit systems cover the following areas, including indicated requirements:

- Location and position:
  - Location of conduit system, such as to avoid being under other parallel networks.
  - Conduit bends of sufficiently large bend radii to avoid damage to cables to be installed in ducts (to not exceed allowable bend radii of cables or sidewall bearing pressure under pulling tension).
  - Satisfactory conduit alignment to avoid protrusions that may damage cable.
  - Minimum separation of supply and communication conduit systems, including 3 in. of concrete or 12 in. of earth, unless the parties agree to lesser separation.
  - Separation of cable conduits from sewer, water, gas, fuel, steam, or other lines to avoid conflicts; conduit shall not enter the same structure (e.g., manhole) as lines transporting flammable material (e.g., gas).
- Excavation and backfill—Satisfactory trench conditions, including smooth trench bottom, absence of large rocks (>4 in.) or sharp edges within 6 in. of conduit, and adequate compaction of backfill.
- For ducts and joints:
  - General design and construction of the ducts so as to avoid damage to cables in adjacent ducts in the event of a cable fault in another duct.
  - Appropriate duct characteristics, including corrosion resistance, absence of sharp internal edges, sufficient strength to withstand expected loads (e.g., dead, live, equipment, water table, frost heave, or thermal effects).
  - Impact loading added for live loads, but reduced by one-third per foot of cover (no impact loading required below 3 ft).
  - Duct restraint methods (e.g., concrete, anchors, or backfill) sufficient to withstand installation, operation, and environmental stresses.
  - Sealing of joints between ducts (resulting in a smooth interior surface for cable installation) and at structure walls (internally and externally to prevent gas entry).
  - Proper support at the entrance to manholes to avoid local shear forces.
- Manholes, handholes, and vaults:
  - Adequate strength of underground structures, including covers, to withstand expected loads (e.g., dead, live, equipment, water table, or frost heave); impact loading of 30% added for live loads.

  - For roadway areas, ability to withstand live loads of large trucks imposing dual-wheel loads of 16,000 lb over an area of 10 in. × 24 in., considering wheel locations resulting in maximum stress in the structure.
  - For nonvehicular areas, the ability to withstand a live load of 300 lb/ft^2 minimum.
  - Means of preventing sewer gas from entering (man-entry) structures and provision of adequate ventilation.
  - Cable supports in manholes and vaults designed and mounted to withstand static and live loads, maintain required clearance between cables, provide a 3-in. minimum space above the floor (unless otherwise protected), and allow cable movement to relieve stresses.

An important consideration in the installation of utility cables for all types of installations (e.g., overhead, underground, or direct-buried) relates to the proper grounding and bonding of appropriate metallic components of such cables and associated equipment and facilities. The details for such procedures are provided in the NESC.

2.2.2 Design and Construction Guidelines

With some exceptions, the NESC rules as described above typically only specify end-point requirements and may not provide the design details necessary to accomplish the objectives. Such details may be provided in engineering manuals of the various utility organizations, as well as by suppliers of associated products.

A relevant document for the telephone industry is the *Outside Plant Systems, Outside Plant Engineering Handbook* (Lucent 1996). This manual contains a summary of planning and design guidelines that are based on the more detailed Bell System practices originally issued by AT&T, and it provides a list of items that should be addressed for underground conduit systems, including the following:

- coordination with other utilities and government agencies regarding their existing and proposed underground facilities;
- possible special construction issues in the location of interest;
- a field survey of the proposed route;
- selection of the permanent location for the underground structures (manholes) based on the following:
  - future requirements (growth);
  - requirements for subsidiary and branch conduits;
  - convenience for interfacing with conduits;
  - compatibility with cable placement operations;

  - future road development;
  - plans for other utilities;
  - special problems (e.g., bridges, railways, or submarine crossings); and
  - location of manholes away from road intersections;
- avoidance of the following:
  - unstable soil conditions,
  - underground structures, and
  - liquid and gas storage facilities;
- safety and convenience of the public and workers;
- individual conduits sized (in diameter) to meet usage requirements;
- selection of conduit material based on minimum total cost;
- manholes and conduit banks constructed for ultimate needs (40-year growth);
- cable-racking capacity compatible with duct capacity;
- conduits pitched toward the manhole;
- proper surface drainage, including avoidance of the following:
  - drainage patterns resulting in possible soil erosion and exposure of the structure and
  - interference with present drainage patterns;
- construction scheduled to avoid periods of the following:
  - cold weather and
  - peak demand on contractors.

The above guidelines indicate that "minimum total cost" should be the criterion in the selection of conduit material. This selection should not be narrowly interpreted to be based only on initial conduit costs (material plus installation), but to reflect the future (life-cycle) cost, including the possible effect on manhole spacing and other construction details, as well as the ability to allow efficient use (cable installation) of the conduit network; see Section 2.2.2.3.

The depth of cover for the conduits should be a minimum of 24 in. for distribution applications (e.g., power supply voltages less than 22 kV and local communication lines) (RUS 2001; NEC 2008).

2.2.2.1 Conduit Sizing. The number of ducts to be provided in the array of conduits depends on the immediate and future needs of the utilities. The decision to use the underground conduit method of construction (mode 2)—in contrast to simpler, lower cost, direct-buried construction (mode 3)—indicates that it is the intention of the utilities to add additional cable facilities in the future, to defer initial cable expenses for predicted growth, or perhaps to conveniently provide new technology, as the need may arise (see Section 1.2). Thus, the planning engineers must attempt to quantify such needs as a means of determining the number of ducts to be provided, as well as the individual size(s) of the ducts. Because of the obvious uncertainty of this process, additional margin should be provided in estimating the ultimate capacity for each utility. Because the conduits are often terminated at different manholes for the communication and power applications (Section 2.1), the conduits may not be readily reallocated between these utilities to attempt to take advantage of the statistical uncertainty in such individual estimates. This limitation essentially requires a greater margin of safety within each category of utilities than may otherwise be required (see Chapter 5).

The use of fiber-optic technology and cables, as well as improved usage of the capacity of coaxial cables, has vastly shrunk the required quantity and individual size of communication cables. Although copper pairs are still widely deployed for local distribution applications, the communication utilities—both traditional telephone and CATV service providers—are currently emphasizing the use of the newer, more compact, and efficient fiber technologies for voice, data, and internet services. This smaller cable greatly reduces the required number and possibly physical size of ducts that may be required for the communication utilities. Conversely, the growing power needs for consumers continually tend to increase to support consumer comfort and various services, including power for advanced communication services. In the absence of innovative technologies, such increased consumption generally requires a greater number of, or physically larger, power cables. Energy alternatives, such as renewable energy, including wind and solar power or more locally distributed power sources, may eventually have an effect on such trends, but they are not anticipated to have a major effect in the near future.

An example of the efficiency and benefits of the fiber-optic communication cables is illustrated by the use of “innerduct,” or “subducts,” coincident with the introduction of fiber-optic cables several decades ago. The small size of these cables, in comparison to typical conduit sizes (e.g., 4-in. conduit), resulted in the widespread deployment of the smaller diameter (e.g., 1- to 2-in.) innerduct, which allows several such subduct paths to be placed within an individual original larger duct. (Additional information is provided in Section 2.2.2.3.) Thus, a single 4-in. conduit that may have originally contained a conventional copper-pair cable serving several hundred customers may now contain several fiber-optic cables, containing many fiber strands, each of which may support many individual subscribers.[2] For this reason, previous engineering planning guidelines for estimating future duct needs (Lucent 1996) tend to be outdated and

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[2] Depending on the application and technology used, multiplexing techniques allow increased efficiency in the use of both copper pairs and fiber strands. In general, however, fiber-optic communication cables allow for transmission capacity orders of magnitude greater than that of the physically larger copper-pair cables.

are likely higher than necessary, although this change will be somewhat offset by the greater number of deployed communication cables along a given distribution or feeder route because of increased competition fostered by the Telecommunications Act of 1996.

2.2.2.2 Section Lengths. Conduit section length refers to the distance between conduit access points, typically corresponding to the location of manholes, vaults, handholes, or other structures. Such lengths depend on a number of considerations (Lucent 1996):

- the location of the intersecting main or branch conduit;
- the interface between the distribution and feeder or transmission cables;
- equipment location;
- splice location, including the length of the cable on the reel;
- physical restraints on manhole location;
- safe location for the manhole; and
- cable placement limitations (e.g., pulling tension).

The last factor, cable placement distance, is strongly dependent on the cable, duct, and equipment used for its installation. Important parameters are the cable size, weight, surface friction, and stiffness characteristics, in combination with the method of placement. In general, communication cables—e.g., fiber-optic—are considerably lighter than power supply cables and, using the proper techniques, may be able to be placed at considerably greater distances, allowing longer section lengths between access points, including manholes. Because manholes for communication access are often separated from manholes for power supply access, this difference is a not a significant issue. Furthermore, if necessary, there are methods and procedures for passing cables through an intermediate manhole without the need to cut or otherwise disturb the cable.

Various guidelines are available for estimating maximum cable placement distance and are typically based on traditional pulling methods (Lucent 1996). Software tools are also available from suppliers (Polywater 2000; Commscope 2003). Chapter 4 discusses various cable placement methods, including more recently introduced techniques, such as blown-cable methods.

2.2.2.3 Conduit Type. Plastic products are currently the dominant product in the market for cable conduit applications, including PVC (Fig. 2-1) and HDPE (Fig. 2-2). Duct sizes of 4- to 6-in. diameter are commonly used.

Rigid PVC pipe (Fig. 2-5) is of relatively low cost and is supplied in discrete lengths in a wide range of diameters. Twenty-foot lengths of 4-in.

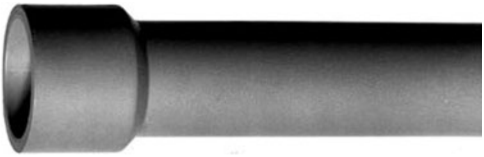

Figure 2-5. Rigid PVC Schedule 40 Conduit (Courtesy of Prime Conduit).

Figure 2-6. Field-Fused PVC.

duct may be conveniently assembled in the field, with the joints sealed by cement, although PVC pipe with gasketed joints is also available. A more recent (proprietary) variety of PVC pipe, including for use in cable applications, may be fused in the field (Fig. 2-6). PVC, similar to most plastic pipe, displays relatively low frictional characteristics; these characteristics facilitate the subsequent placement of communication or power cables. PVC conduit is available in various varieties and wall thicknesses, corresponding to designation types DB, EB, B, C, and D, and Schedule 40 and Schedule 80.

PVC types DB and EB may be used for power or communication, and they satisfy NEMA TC 6 and 8 and ASTM F512 standards (NEMA 2003a; ASTM 2006). Types B, C, and D are typically used for communication applications, meeting Telcordia CA08546 and NEMA TC 10 requirements (Telcordia 1985; NEMA 1993). The thicker Schedule 40 and 80 sizes are typically used for electric power applications and satisfy NEMA TC 2 requirements (NEMA 2003a). Rigid sweeps of various angles are available in the various types to accomplish route bends (Fig. 2-7).

Figure 2-7. Rigid PVC Sweep (90° Bend) (Courtesy of Net-Tech Distributing).

Types EB and B PVC conduit have thin walls and are generally encased in concrete. Types DB and C have thicker walls and may be encased in concrete or buried with select backfill. Type D conduit is of greater wall thickness than Types B or C, white, and designed to be used in exposed installations. Schedule 40 is used for typical underground applications; Schedule 80 has extra heavy wall thickness and is used for applications subject to physical abuse, including aboveground installations.

Polyethylene duct is available in continuous lengths on a reel, in diameters as large as 6 in., and joints may be fused in the field, as necessary, although mechanical couplers are available for the smaller sizes (e.g., ≤ 2 in.). Requirements for mechanical couplings are provided in ASTM F2176 (ASTM 2002), including specifications for maximum air leakage for applications with blown-cable installation systems (Section 4.3).

HDPE duct is available in a variety of strengths (pipe wall thickness) and configurations. Typical HDPE duct for underground conduit applications is of a smooth-wall variety for both interior and exterior surfaces, but other innovative types are also available. Figure 2-8 shows a hybrid design, with corrugated outer surface and smooth-wall interior, available in discrete lengths of 20 or 40 ft. Conventional polyethylene pipe products are generally required in greater wall thickness than equivalent-strength PVC products, but they offer advantages in allowing installation in continuous lengths and flexibility for negotiating route bends, obviating the need for inserting rigid sweeps of discrete angles. They also display low frictional resistance during cable installation. ASTM F2160 provides detailed specifications for HDPE conduit for communication or power cable applications (ASTM 2008b). To be compatible with the recommendations of the American Public Works Association (APWA 2000), duct for power and communication cables should optimally be red or orange, respectively, in solid or striped

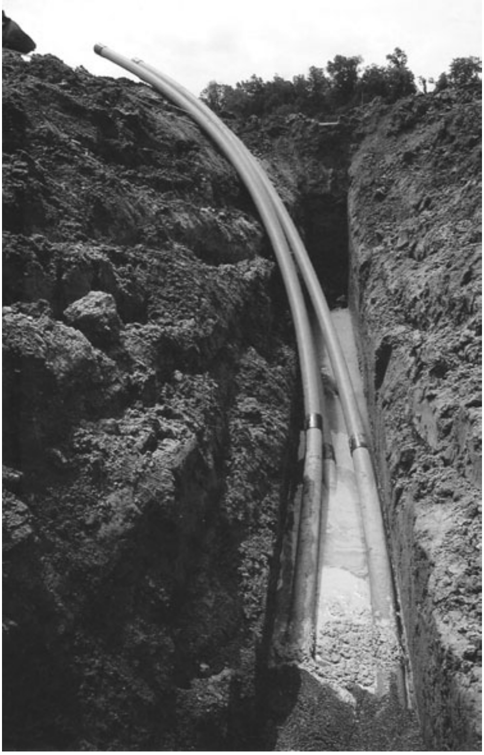

Figure 2-8. HDPE Corrugated Exterior, Smooth-Wall Interior Conduit (Courtesy of A-D Technologies).

patterns. For aboveground installations exposed to ultraviolet radiation, colored stripes on black duct may be selected because black duct may have greater UV resistance. In general, the APWA recommends the following colors for duct:

Electric power	red
Communication, alarm, or signal	orange
Gas, oil, steam, or petroleum	yellow
Water (potable)	blue
Sewer, drain	green
Reclaimed water, irrigation	purple

Although it is recognized that such color codes are not always maintained, it is recommended, for safety, that the color yellow not be used for cable installations because this is the uniform color code for natural gas applications.

Additional information regarding the use and installation of polyethylene pipe and conduit for communication and power cable applications is provided in *The Plastics Pipe Institute Handbook of Polyethylene Pipe* (PPI 2006).

In special cases, steel pipe may be selected, including trenchless installations for which the conduit must be pushed (e.g., using pipe jacking or pipe ramming) or where additional strength or protection is required. Steel pipe may be used as a larger outer casing at railway and road crossings, as may be required by transportation authorities. In such cases, the diameter of the steel casing would depend on the number of cables or ducts to be contained within. Requirements for providing such encasement at road and highway crossings are provided by the transportation industry (FHWA 1993; AASHTO 2005).

In addition to serving as the main duct path, HDPE is often used in smaller diameters, providing several innerduct paths to be placed within the larger duct, thereby resulting in more efficient use of the conduit system, as discussed in Section 2.2.2.1 and illustrated in Figs. 2-9 and 2-10. Innerduct is available in various configurations, including smooth-wall, ribbed, and corrugated, as well as prelubricated, to facilitate the subsequent installation of the cable, and it may also contain preinstalled pull line. Also, HDPE ducts containing preinstalled cables (cable-in duct) may be provided by suppliers to provide mechanical protection for the initially installed enclosed cables, while eliminating the need to subsequently install the cables in the field.

Industry requirements for innerduct for fiber-optic applications are provided by Telcordia Technologies (Telcordia 1995). Some suppliers

Figure 2-9. HDPE Innerduct (Courtesy of Lamson Pipe Company).

Figure 2-10. HDPE Conduit with Three HDPE Innerduct Paths Plus Cables (Courtesy of Innerduct.com).

provide methods for grouping several smaller tubes without an external conduit casing, which are then installed as a unit, eliminating the need to subsequently place innerducts within an outer conduit. Such products may represent discrete lengths of PVC tubes (Fig. 2-11) or continuous lengths of HDPE duct. More recent alternatives to conventional plastic pipe innerduct include lightweight, convenient fabric matrices, which have several pockets that provide multiple subduct paths within the larger main duct (Fig. 2-12). This choice is a lightweight, easily installed option but is not compatible with some methods of cable installation (see Chapter 4).

Advances in the installation of fiber-optic media continue to evolve, including the introduction of microducts, representing extremely small (e.g., 5 to 16 mm) diameter plastic tubes designed for multiple placement within larger ducts for facilitating the efficient installation of very small diameter, lightweight, easy-to-handle fiber-optic members. In combination with such fiber-optic units, microducts can be installed in occupied ducts, allowing increased capacity. Multiple microducts preinstalled in ducts (Fig. 2-13), similar to multiple innerducts in conduit, can also be installed in conduit systems or buried directly in the ground. In addition,

Figure 2-11. Grouped PVC Innerducts (Courtesy of Prime Conduit).

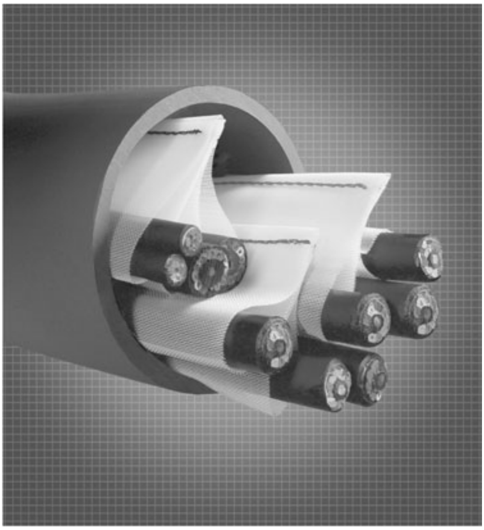

Figure 2-12. Conduit with Multiple Fabric Subduct Paths Plus Cables (Courtesy of the Maxcell Group).

multiple microducts may be cabled and jacketed. Installation methods include those discussed in Section 3.2.2 and in Chapter 4.

2.2.2.4 Construction. Various products are available to help maintain desired or required separation distances between ducts, as illustrated in

Figure 2-13. Microducts within Innerduct (Courtesy of A-D Technologies).

Figs. 1-2(a) and 2-1. The corresponding backfill requirements may include the use of concrete or well-tamped earth, including compacted sand or granular backfill in the immediate vicinity of the ducts. As a guide, the estimated volume of sand or granular backfill should include an additional allowance of approximately 10% for compaction. For nonconcrete-encased installations, the construction procedures for the placement of the conduits should be consistent with industry guidelines, including that recommended in ASTM F1668 (ASTM 2008a). For construction within roadways, local agencies may have specific backfill and paving requirements.

The trench construction operation and procedures should be compatible with the rules of the Occupational Safety and Health Administration (OSHA 1970) and the National Electrical Safety Code (IEEE 2007). The NESC states the following:

> When a worker is required to perform tasks in trenches or excavations where a cave-in hazard exists or the trench or excavation is in excess of 1.5 m (5 ft) in depth, shoring, sloping, or shielding methods shall be used to provide employee protection.

In addition, the following NESC rules should be observed during construction (IEEE 2007):

- Before using open flames in an excavation in the vicinity of gasoline service stations, the atmosphere must be confirmed to be safe or cleared of combustible gases or liquids.

- During excavation,
    - buried utilities in the vicinity shall be located;
    - if boring methods (e.g., directional drilling) are used and the bore path crosses existing utilities, the latter should be exposed at the crossing;
    - mechanized equipment should not be used close to existing buried utilities;
    - hand tools used for excavating in the vicinity of energized supply cables must be equipped with nonconductive handles;
    - if a line that transports gas or flammable material is broken or damaged, the employees must do the following:
        - leave the excavation open,
        - extinguish all flames,
        - notify the proper authority, and
        - keep the public away until the condition is under control.

Manholes may be precast or cast in place. In general, it is preferred to use precast manholes because of their lower cost, quality control, and more rapid installation. Precast manholes may be provided with various convenient features, such as terminators for plastic duct. However, in some cases—including required sizes not compatible with available products, unusual design, or where obstructions prevent the placement or installation of a precast unit—it may be necessary to cast the manhole in place.

Manholes should be located consistent with the recommendations provided in Sections 2.2.1 and 2.2.2. In addition, the manhole design, construction, and placement should meet the following requirements (IEEE 2007):

- They must contain sufficient working space, typically
    - a 3-ft minimum clear horizontal working space and
    - a 6-ft minimum clear vertical working space.
- Access openings, typically, should have
    - a 26-in. minimum round opening or
    - a 26 × 22-in. minimum rectangular opening.
- Access openings must be free of protrusions that may injure personnel or prevent rapid egress.
- When practical, openings should be located
    - outside of the paved roadway or highway,
    - outside of street intersections and crosswalks, and
    - not directly above cable or equipment locations.
- Covers should
    - contain identification of ownership or the type of utility and
    - be designed or restrained so that they

        - □ are not easily removable without proper tools,
        - □ cannot fall into the manhole, and
        - □ do not contact cable or equipment.
- Suitable means should be provided to
    - o limit entry of sewer gas and
    - o supply adequate ventilation for structures that open into public enclosed areas.

Once the manhole is installed or constructed, including the interfaces with the ducts, the network should be verified to be functional by passing a test mandrel, of diameter one-quarter inch less than the inside diameter of the duct path, through several sample ducts (RUS 2001). The individual ducts should then be plugged to minimize water or debris entry (see Section 2.3).

Although typical manholes are subject to possible water intrusion and atmospheric contamination, some underground structures are deliberately designed to maintain a controlled environment. For example, controlled environment vaults (CEVs) contain pumps, ventilation and heating systems, and atmospheric monitors to maintain conditions that are satisfactory for sensitive electronic telephone hardware and equipment, as well as to provide a comfortable working environment (Telcordia 1994). Part of the CEV is aboveground, including the ventilation system, and the site must be selected to avoid the possibility of historically possible flood levels entering through the air vents. In general, CEVs are precast and are not intended to accommodate cables that merely pass through the enclosure, which are generally supported via separate manholes in the vicinity.

2.3 OPERATION AND MAINTENANCE

2.3.1 Conduits

In general, it is important to seal ducts to prevent or minimize the entry of gas or water into the ducts or underground structure. Ducts must be clear of water or debris for a cable to be placed within. Contaminated ducts must be cleaned before cable placement.

A variety of auxiliary hardware products are available to support the use and maintenance of underground conduit systems, including conduit and duct plugs, pull line or tape, duct rodders, and cable grips. Figure 2-14 illustrates several types of plugs to eliminate or reduce the entry of water or debris into the duct pathways, protecting the duct passages. Plugs are available in a variety of configurations, including those for sealing a vacant or occupied duct.

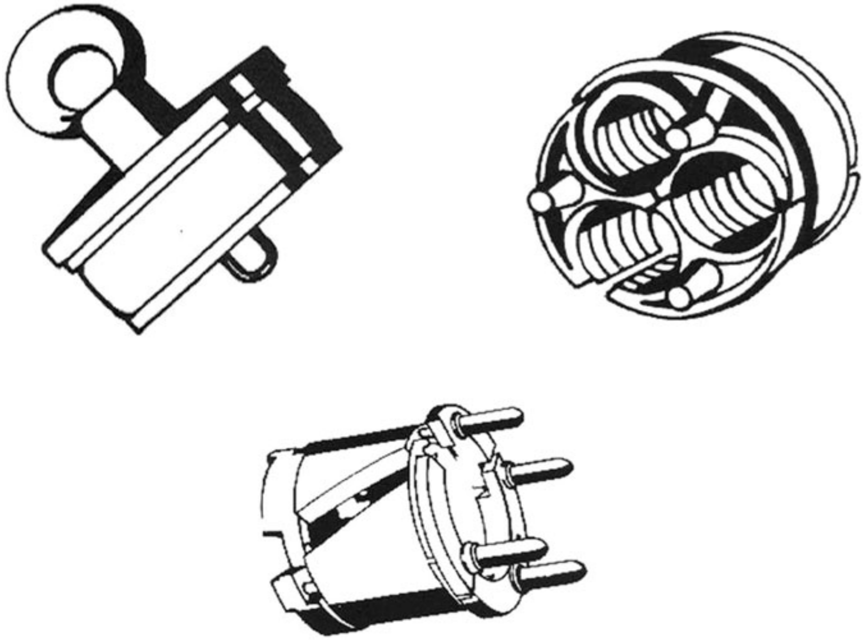

Figure 2-14. Conduit Plugs (Courtesy of TVC Communications).

Figure 2-15 illustrates duct rodders used for pushing through an empty (or partially occupied) duct for the purpose of pulling back a rope for subsequently pulling in a cable (see Section 4.1). A rodder may also be useful for aiding in cleaning a duct into which debris has infiltrated.

2.3.2 Manholes

The primary functions of the manhole or other underground structure are to allow access for placing the cables along the duct paths and to house the related terminal equipment or splices.[3] To use and manage the operation of the manhole efficiently, the various utility cables that are accommodated within the structure must be properly organized. The cables include those that are terminated in splice cases or equipment, as well as those that only pass through the structure without any local

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[3] An auxiliary use allows a utility locator access to put a toroidal clamp around a cable for locating it between the structures.

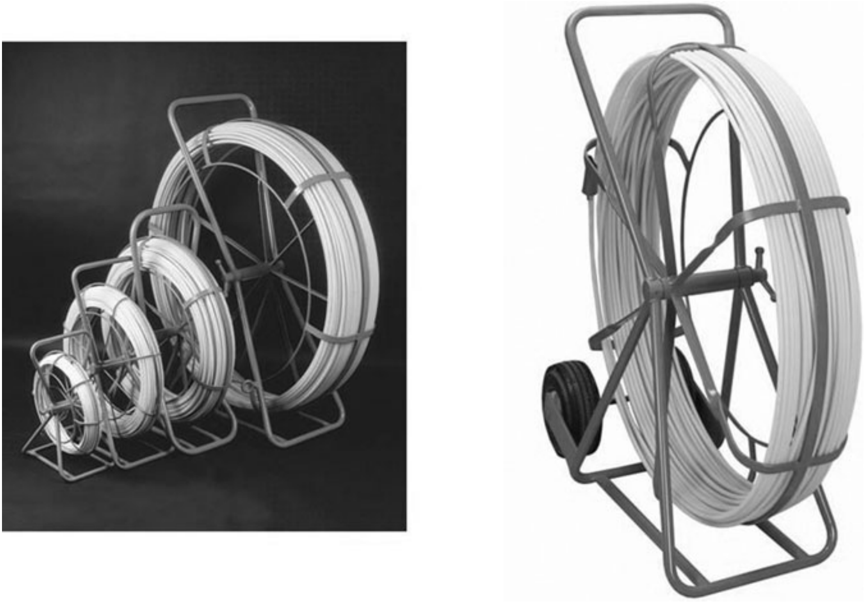

Figure 2-15. Duct Rodders (Courtesy of Condux International).

connections. As a general rule, the cable racks should be populated from the bottom up (Lucent 1996). For multiple racks, the outer (wall-mounted) racks should be populated before those located toward the center of the manhole. Splice cases may typically be mounted directly on the racks. Duct selection should be such as to avoid cable crossovers between the duct entrance and the support racks and to avoid blockage of future access to vacant ducts.

The NESC provides specific safety-based rules applicable to the handling and location of the communication and power supply cables to be placed within the conduit system and underground structures. These rules relate to proper grounding and provision of electrical protective devices (e.g., surge arresters), as well as rules related to the use of joint use of manholes:

- Manholes and vaults may be jointly used for communication and power supply if all parties agree.
- Electric supply cable and communication cables must be in separate ducts, unless they are operated and maintained by the same utility.
- Communication cables may use the same ducts if the utilities involved agree.

- Communication and power supply cables should, if possible, be racked on separate walls, and crossovers should be avoided.
- If communication and power supply cables are on the same wall, the power cables should be mounted below the communication cables.
- Clearance between electric supply and communication cables ranges from 6 in. (for ≤ 15 kV supply voltage) to 24 in. (for > 120 kV supply voltage), unless barriers are installed and the utilities agree.
- Individual cables shall be clearly identified.

The National Electrical Safety Code also specifies work rules aimed at protecting communication and power utility employees during operations. These rules require the following:

- guarding manhole and street openings, including barriers and covers;
- before entry, testing for gas in manholes and unventilated vaults, including
  - combustible or flammable gases and
  - oxygen deficiency (unless forced ventilation is continuously provided);
- provision for adequate continuous supply of air while in underground structures;
- regarding flames in manholes,
  - no smoking in manholes and
  - extra precautions to ensure adequate ventilation when open flames are required in structures; and
- when communication employees are working in a joint-use manhole, another employee must be available on the surface to render assistance, as may be required.

In addition to the basic safety rules required by the NESC, further precautions are specified within the utilities. For example, the Telcordia *Blue Book—Manual of Construction Procedures* (Telcordia 2007) provides the following general safety procedures for the telephone industry when working in a manhole:

- A ladder must be used for entry (i.e., no climbing on cables or other equipment).
- No open flames are allowed in or near a manhole, regardless of atmospheric test results.
- Any equipment that may produce sparks (e.g., electric tools or high-voltage test sets) should not be used.
- Light bulbs, if present, must have a protective cover.

- Temporary platforms must not be supported on cables.
- No smoking is allowed near an open manhole.
- No cover shall be placed over an entrance unless it is a minimum of 4 ft above the surface of the opening, with the exception of protective screens.
- Proper housekeeping is required, including the following:
  - after completion of tasks, all debris must be promptly removed and
  - combustible material shall not be allowed to accumulate.

Additional rules apply to cable installation operations, such as the following:

- Pulleys and other equipment used to install a cable must not contact other (existing) cables.
- Materials used to facilitate cable installation, preparation, or other operations (e.g., lubricants or liquids for leak detection for pressurized cable systems) must be compatible with the cable materials.

For joint-use applications, the agreement between the owner of the manhole and other tenants or occupants provides additional rules. For example, depending on the owner, there may be restrictions on the placement of power supply units or amplifiers within a manhole.

The individual utilities may provide additional detailed practices and procedures, including those provided in the original Bell System practices, for working in underground structures and the installation and termination of cables. For example, the Telcordia *Blue Book* provides specific detailed procedures for testing manhole atmosphere and providing proper ventilation, placement of cable identification markers, and methods for sealing ducts (Telcordia 2007).

2.4 ISSUES

As is apparent from the above description and information, underground conduit systems provide extensive facilities for supporting the initial placement and future upgrade of cables, as well as convenient belowground facilities for cable splicing and containing associated equipment. Such duct networks and structures represent a major investment in materials, labor, and real estate because of the relatively large underground structures, as well as continuing maintenance and operational expenses. Nonetheless, underground conduit systems are the appropriate solution for many applications. For portions of the communication or power supply network designed and operated on the basis of planned future additions of cables, including areas where it is undesirable to have any aboveground facilities (e.g., poles, cabinets, pedestals) or areas where it impractical to do any digging or construction for future maintenance or additions (e.g., urban areas), underground systems are often the only practical alternative. (Chapter 3 discusses direct-buried construction methods, which are practical alternatives for many applications.)

In addition to the significant overall investment, other issues arise in the operation and maintenance of underground conduit and manhole facilities. There are safety issues related to the entry of combustible or poisonous gas into the manhole, as indicated in Section 2.3.2, as well as environmental issues associated with the proper disposal of storm water that may inevitably accumulate in such enclosures. The disposal procedures must be compatible with federal and local regulations.

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3

DIRECT-BURIED SYSTEMS

3.1 GENERAL

Lady Bird Johnson, the wife of former President Lyndon Baines Johnson, was dedicated to beautifying America, and many of the results of her efforts may be seen along our streets and highways. Based on her vision in the 1960s, the utilities—particularly the telephone industry—accelerated their plans for placing new cable plant belowground, in a direct-buried mode, minimizing the usage of unsightly "telephone" (i.e., utility) poles. The increased application of belowground facilities also provides potentially more reliable and safer facilities, with respect to vulnerability to storms and vehicular traffic. The basis for many of the current buried-cable procedures are again found in the original Bell System Practices. Similar to underground conduit facilities, the NESC specifies related safety rules (IEEE 2007).

Figure 1-2(b) illustrates the relatively simple construction process associated with the direct burial of utility cables in a trench. Because the cables are typically in direct contact with the soil, it is essential that the cables be robust. In general, such cables are therefore designed to be waterproof, electrically insulated,[1] and mechanically protected by a tough outer jacket or armor. The primary advantage of direct burial is the relatively low material and construction costs compared to underground conduit systems and the minimal real estate needs (e.g., there are no large underground structures). The local distribution portion

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[1] Power cables, for example, need not be insulated for overhead construction, in which the phases are physically separated on the pole.

of the power and communication networks, and the corresponding service lines directly connected to the customers, often use direct-buried construction. The major disadvantage of direct-buried construction is the inherent lack of upgradability in the event that new or additional cables are required.[2] Therefore, the utility engineer must plan and design the buried facilities, including the cables that must be permanently placed in the ground, to meet the ultimate anticipated needs of the community served by the network. Unfortunately, although this philosophy is often successful, it is not uncommon for new cable to be required for various reasons, which results in the need for additional construction, often under more difficult conditions than those during the original construction phase, when conventional open trenching was acceptable.

The buried cables are placed at appropriate depths, sometimes in a shared (joint-usage) trench, and connected at equipment or hardware locations, including that from which branch cables or service wires may be routed to individual customers, small businesses, or other buildings. The equipment or hardware may be mounted in handholes installed at grade (similar to those possibly used in underground conduit systems; e.g., Fig. 2-4) or in aboveground cabinets or pedestals (Figs. 3-1 and

Figure 3-1. Aboveground Pedestal (Courtesy of Pencell Plastics).

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[2] The feeder or transmission portions of the networks, corresponding to longer distances and typically designed to be reinforced or upgradable, are often constructed using underground conduit systems.

Figure 3-2. Telephone Cabinet (Courtesy of 3M).

3-2). The equipment may represent electrical power transformers; terminals for accessing communication cable pairs, fibers, or coaxial cables; amplifiers; or power supplies. Cable splicing hardware may also be present.

Although the application of low-cost, direct-buried construction is based on the general assumption that the initially placed cables would provide sufficient service indefinitely, there are various reasons why new cables must eventually be required. These reasons include the introduction of new technology (e.g., fiber-optic communication), insufficient capacity, or premature cable degradation or damage. In anticipation of such events, it is not unusual for a particular utility to supplement its buried cables with a spare (vacant) duct or possibly for the utility to place its cables within a conduit, recognizing that such cables may be subsequently removed and replaced, if necessary. Such practices, however, are not uniformly applied in a consistent manner or practiced across all utilities and locations. The use of an individual duct by a utility, not part of an integrated system of ducts and belowground structures (e.g., manholes, handholes, and vaults), is generally considered to be "direct-buried" plant (vs. "underground conduit") and subject to the appropriate rules of the NESC, as discussed in Section 2.2.1.

Although trenching is the most common form of direct-buried construction, alternate procedures include plowing and various methods of boring, such as directional drilling, as in Section 3.2.2.3.

The rules and practices related to the direct burial of utility cables are provided in this book to provide additional background for understanding the design requirements for variations that include the usage of a duct or conduit in some manner. This background is especially important with respect to hybrid systems (belowground cable networks), such as those discussed in Chapter 5.

3.2 DESIGN AND CONSTRUCTION REQUIREMENTS

This book emphasizes joint-usage applications in which communication and power supply cables share facilities (common trench) because of the corresponding space efficiency and cost-effectiveness. There is also less likelihood of damage during construction because of a reduction in the number of separate digging operations. For such applications, however, coordination is required among the parties to expedite placement of individual cables, consistent with their position within the trench, and to help ensure that subsequent backfilling of the trench is accomplished as soon as possible.

In general, the rules and practices in this section refer to the installation of bare cables placed within the ground, without supplementary protection, as well as "direct-buried supply and communication cables installed in duct that is not part of a conduit system," as specified in the National Electrical Safety Code (IEEE 2007).

3.2.1 Safety-Based Requirements

The NESC rules provide the following requirements (IEEE 2007):

- Cable properties:
  - effective grounding of cables operating at > 600 V and
  - appropriate marking and designation on the outer jacket.
- Cable location and routing (to the extent practical):
  - where subject to minimal disturbance;
  - installation in a straight, direct path, with sufficiently large bend radii to avoid damage;
  - allowance for safe access for construction, inspection, and maintenance;
  - submarine crossings selected or installed to be protected from erosion; and
  - avoidance of undesirable locations, such as
    - unstable or corrosive soil or other problematic conditions (or protected as necessary),
    - directly beneath the foundation of a structure or building and
    - longitudinally beneath railroad tracks or traveled surfaces of streets or roads.
- Installation (see Section 3.2.2):
  - trenching consistent with the following practices:
    - smooth trench bottom,
    - usage of a protective bottom layer (of well-tamped backfill) in rocky conditions,

    - absence of large rocks or damaging materials within 4 in. of cable,
    - adequate compaction of backfill, and
    - machine compaction avoided within 6 in. of cables;
  - plowing using appropriate equipment and operation to avoid excessive loads (e.g., bending, sidewall pressure, or tension) on cable during installation; and
  - boring using proper cable protection provided for soil with rocks and other debris that may damage cable during pull-in or subsequent usage.
- Burial depth: minimum depth of cover for power supply cables[3] (unless supplemental protection is provided):
  - 24 in. for ≤ 600 V,
  - 30 in. for 601–50,000 V, or
  - 42 in. for > 50,000 V.
- Shared ducts:
  - power supply and communication cables not installed within the same individual duct (unless they are all operated by the same utility) and
  - communication cables from different utilities may be placed within the same duct if all parties agree.
- Separation between utility lines:
  - general (default) requirement of a 12-in. minimal radial separation between power supply and communication cables, as well as between other utility lines (e.g., water, sewer, or gas) and structures:
    - sufficient radial separation to allow maintenance to either utility cable without damage to another,
    - sufficient support at the crossing of cables above or beneath a structure to avoid damage to either (possibly via sufficient vertical separation), and
    - thermal protection (from steam or cryogenic lines) via adequate separation or a thermal barrier;
  - allowable random[4] (<12 in.) separation between electric power supply and communication cables under specific conditions, providing that all parties involved are in agreement, subject to the following:

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[3] Secondary power (service) lines are typically 120 or 240 V; primary distribution power lines are typically < 22 kV.

[4] Random separation indicates that cables are buried without any deliberate separation, including direct contact. Although "random separation" indicates that cables of different utilities may be close, such cables may not be wrapped around each other.

- minimum radial separation of 12 in. between power supply or communication cables and lines that transport steam, gas, or other flammable material;
- electric power supply circuits > 300 V must be promptly deenergized on fault;
- cables of different supply circuits may be buried without deliberate separation;
- cables of different communication circuits may be buried without deliberate separation;
- electric power supply cables and communication cables may be buried without deliberate separation if the following conditions are met:
    - grounded electric power supply systems ≤ 22 kV (to ground) and ungrounded electric power supply systems ≤ 5.3 kV (phase to phase), and
    - cables operating at > 300 V (to ground) appropriately constructed (e.g., with metallic shields), grounded, and bonded;
- electric power supply cables and communication cables may be buried without deliberate separation from nonmetallic water and sewer lines.

Additional details, including bonding and grounding requirements for random separation of power and communication cables, are provided in the NESC.

3.2.2 Design and Construction Guidelines

There are several general methods currently available for the direct burial of cables:

- trenching,
- plowing, and
- boring (e.g., using piercing tools or horizontal directional drilling).

For any belowground construction activities, the "one-call center" or its equivalent must be notified at least 48 hours before subsurface construction. The center notifies other utilities or parties in the area to identify, locate, and mark their facilities in the vicinity of the planned construction route before initiation of construction. It is strongly recommended that the latest subsurface utility engineering (SUE) methods be adopted, as appropriate for the area under construction, or reconstruction. *Standard Guidelines for the Collection and Depiction of Existing Subsur-*

face Utility Data, CI/ASCE 38, provides additional information (ASCE 2002).

3.2.2.1 Trenching. Open-cut trenching is the procedure commonly used for installing new utilities of any type belowground, especially in new-build areas for which surface restoration or damage to existing utilities and structures is not an issue. Figure 3-3 shows a typical trenching operation.

The current discussion regarding direct-buried construction focuses on the placement of bare cables within the trench or those within a flexible duct, as appropriate. In addition to the basic safety requirements provided in Section 3.2.1 for such construction, additional practices are specified within the industry and by the utilities. For example, the Telcordia *Blue Book—Manual of Construction Procedures* (Telcordia 2007) provides requirements and guidelines for buried cable placement, including joint usage (sharing)[5] of a common trench:

- General guidelines:
    - typical distribution cable placement longitudinally along roads or highways, within public rights-of-way or private easements, including along front or rear property lines and between the curb and sidewalk;
    - service cable or wire placement along property lines and across the property of the subscriber receiving the designated service;

Figure 3-3. Open-Cut Trenching (Courtesy of Ditch Witch).

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[5] Requirements specified in the Telcordia *Blue Book—Manual of Construction Procedures* may be superseded by formal joint-usage agreements between the parties sharing a common trench. However, the NESC basic safety rules may not be violated.

  - route selection to minimize likelihood of future disturbance because of future unrelated construction activities (e.g., road widening);
  - avoidance of routes vulnerable to erosion and potential reduction of desired depth of cover for cables;
  - route selection to provide as direct a path as possible, while avoiding excessive damage to roots of trees or other vegetation;
  - where feasible, splices located near obstacles or where cables feed through pipes (e.g., beneath roadways); and
  - compliance with OSHA safety requirements (see Section 2.2.2.4).
- Trench conditions:
  - similar to NESC, but also requires absence of large rocks or damaging materials within 6 in. of cable;
  - special care in providing level trench bottom when burying flexible duct (e.g., innerduct), to minimize duct path undulations and curvature; and
  - belowground pipe recommended for cable passage beneath sidewalks, streets, or other obstacles.
- Burial depth for communication cables—minimum depth of cover:
  - for copper cable,
    - 12 in. for service wire,
    - 24 in. for feeder or distribution cable, and
    - 30 in. for toll or trunk cable;
  - for fiber cable,[6]
    - 18 in. for service wire;
    - 24 in. for feeder or distribution cable; and
    - 30 in. for toll or trunk cable.
- Cable placement:
  - careful placement on the bottom of the trench;
  - absence of tension;
  - maintenance of minimum bending radii, as specified by the supplier (typically 10–20 times the cable diameter);
  - avoidance of equipment that may cause sheath abrasion; and
  - avoidance of placing a reverse bend in the cable (opposite of the original reel curvature).
- Miscellaneous:
  - permanent markings (aboveground and buried) installed to indicate the presence of belowground facilities:

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[6] The Lucent handbook (Lucent 1996) recommends 36 in. as a general depth of cover for fiber-optic cable.

    - aboveground markers that indicate ownership and contact information and
    - warning tape buried at a 12-in. minimum above the cables and
  - proper bonding and grounding of cables, consistent with NESC rules.

These NESC and Blue Book rules provide basic trench design rules, as illustrated in Fig. 3-4 for a trench containing distribution cables and Fig. 3-5 for a trench containing service cables and wires. In general, joint trenching of power and communication cables has been limited to distribution cables (Lucent 1996).

Figure 3-6 shows an implementation of the basic rules illustrated in Fig. 3-4, incorporating a 12-in. minimum vertical separation between the electric power supply and communication cables in a distribution trench application. Figure 3-7 uses a 12-in. horizontal separation.

Figure 3-8 illustrates an application in which the rules for random (nondeliberate) separation are satisfied as specified in Section 3.2.1, such that the cables may be placed close to each other.

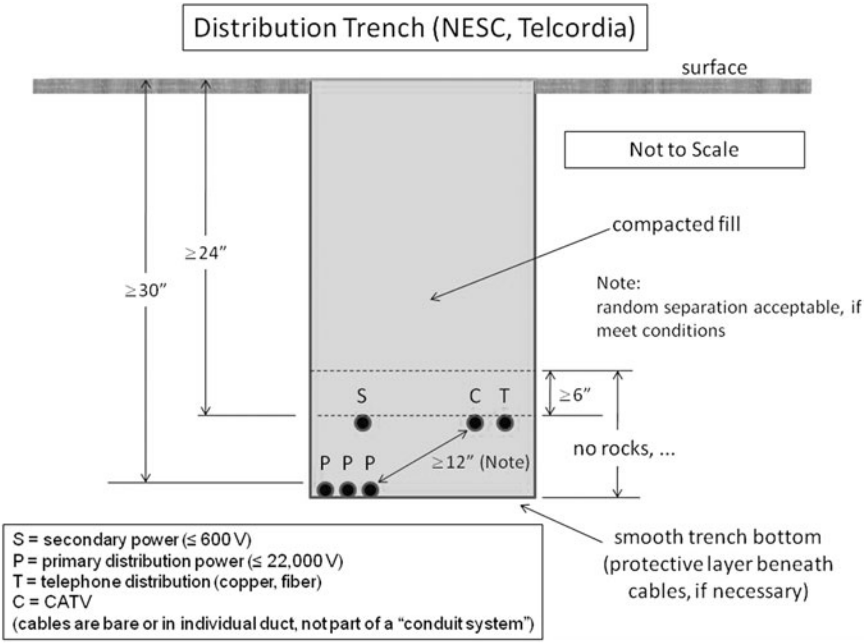

Figure 3-4. Basic Requirements for Direct-Buried Distribution Cable Trench.

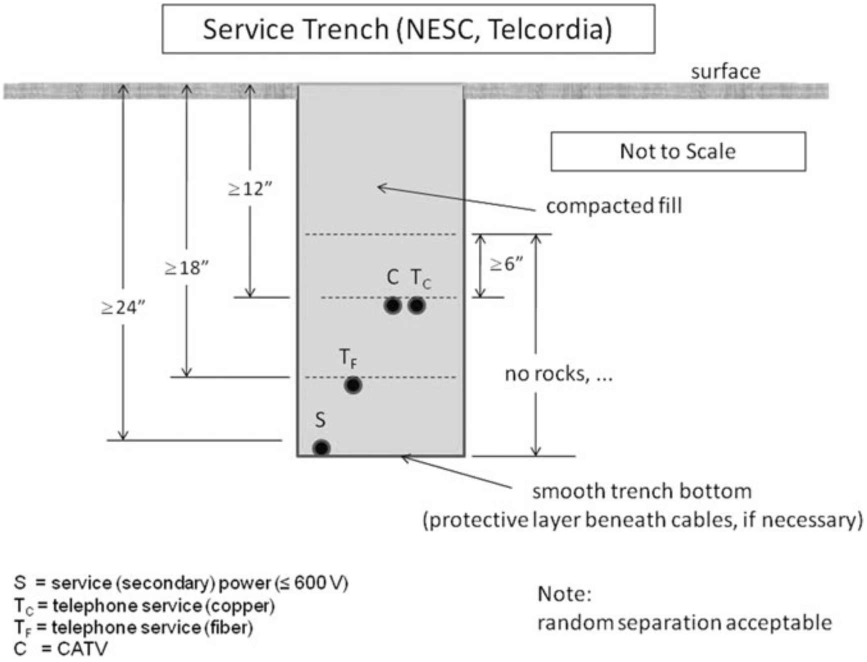

Figure 3-5. Basic Requirements for Direct-Buried Service Wire or Cable Trench.

The Rural Utilities Service (RUS), an agency of the U.S. Department of Agriculture, provides additional requirements for electric distribution lines for compliance in RUS-financed facilities (RUS 2000):

- Trench conditions:
  - trenches as straight as possible;
  - when installing more than one cable at a specified depth, extra depth (and width, as appropriate) provided to account for possible soil falling into trench during placement of initial cables; and
  - pedestal stakes driven into the ground before cable placement.
- Cable placement:
  - cables placed by hand;
  - sufficient slack (minimum of 24 in.) at risers and aboveground equipment terminations;
  - maintenance of minimum bending radii:
    - 12 times the cable diameter for primary cables and
    - 6 times the cable diameter for secondary and service cables; and
  - cables properly tagged at termination points.

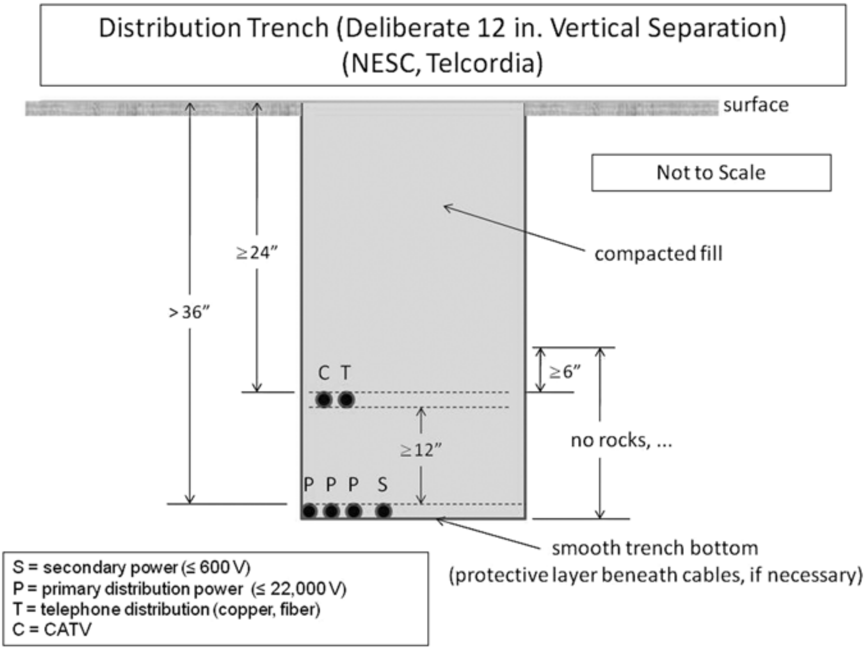

Figure 3-6. Example Implementation for Direct-Buried Distribution Cable Trench (with a Deliberate 12-in. Vertical Separation).

- Splices:
  - reliable hardware (e.g., premolded rubber, heat- or cold-shrink, and correct voltage rating);
  - splices preferably limited to a minimum of 2,000 ft of cable; and
  - absence of bends within 12 in. of a splice.
- Backfilling:
  - first 6 in. of backfill free of rock (e.g., 2 in. of clean fill below the cable plus 4 in. above);
  - careful compaction (with minimal voids) to avoid damage to the cable; and
  - backfill tamped to slope away from equipment enclosures.

Additional details regarding terminations of electric primary and secondary power cables, as well as grounding, corrosion protection (sacrificial anodes), cable location markers, and safety signs are provided.

Figure 3-9 shows one of several possible trench configurations recommended by the RUS.

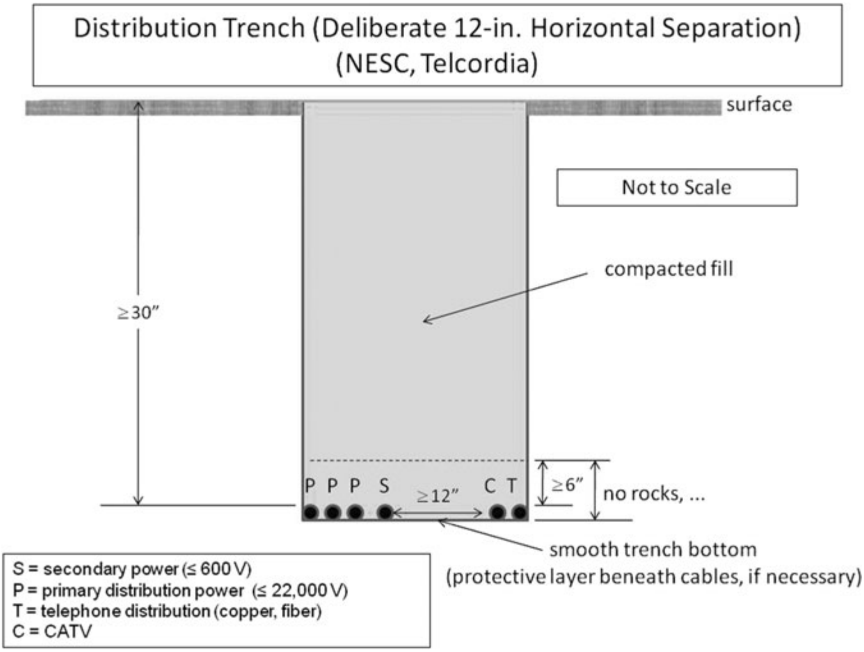

Figure 3-7. Example Implementation for Direct-Buried Distribution Cable Trench (with a Deliberate 12-in. Horizontal Separation).

3.2.2.2 Plowing. Cable plowing is a rapid, efficient, and cost-effective means of installing utility cables, while also resulting in minimal surface damage. In comparison to open-cut trenching, the surface damage is insignificant and is often difficult to detect after a short time. The plowing technique may be used to place various types of cables and wires, depending on the local conditions, desired depth of cable placement, and size of equipment available. There are two types of cable-plow procedures: conventional chute plowing and pull plowing. In both cases, the procedure uses a tractor with a plow blade attached at the rear that rips a relatively narrow slit in the soil, through which the cable is inserted.

The length of the plow blade determines the depth of burial. For given soil conditions, greater depths require larger, more powerful tractors with greater horsepower. Similarly, more difficult soil conditions (e.g., rocky) require larger, more powerful machines. Typical plowing operations use vibratory equipment in which the plow blade penetrates through the soil in a chopping motion, allowing physically smaller tractors to accomplish the equivalent depth and progress of larger, heavier machines that rely primarily on the direct static penetrating force of a nonvibratory plow

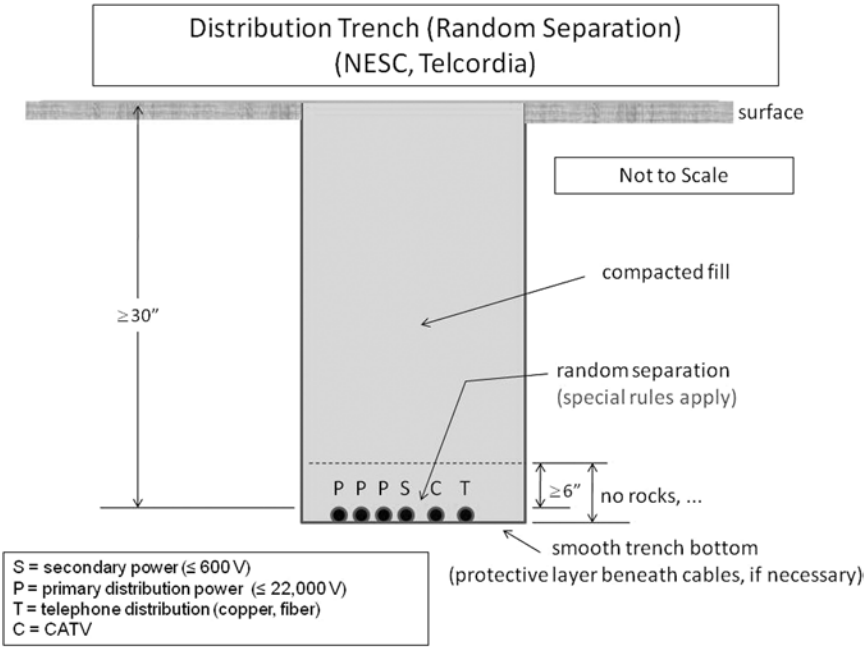

Figure 3-8. Example Implementation for Direct-Buried Distribution Cable Trench (with Random or Nondeliberate Separation). Special Rules Apply.

unit. The net required horsepower, however, is not necessarily reduced because of the power required to operate the vibratory unit.

The primary hurdle in the feasibility of this low-cost procedure is the presence of obstacles along the path, including surface structures and natural obstacles. Assuming that the procedure is feasible, the combination of soil conditions and available equipment (e.g., size and horsepower) determines the ability to meet the design criteria, such as the burial depth. An additional consideration is the number and type of utility cables being installed. For joint-trench operations, or in a new-build situation in which surface restoration is not an issue, the advantages and flexibility of open-cut trenching may outweigh the advantages of cable plowing.

The NESC specifies that plowing procedures and equipment should be such as to avoid damage to cables because of soil containing rock or solid material or bending, sidewall pressure, or excessive tension.

In conventional chute plowing, the cable is fed from a reel, supported on the mobile tractor, through a slot in the plow blade mounted at the rear of the tractor. The chute has a curved configuration that allows the

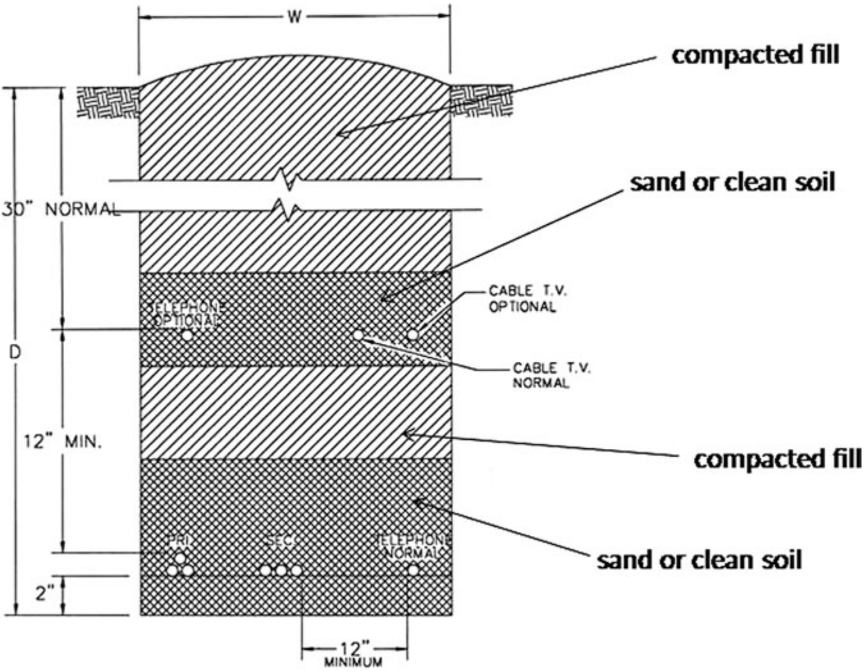

Figure 3-9. RUS Design for a Distribution Cable Trench (with Deliberate 12-in. Separation). Source: RUS 2000.

cable or wire to enter vertically into the top and exit horizontally at the bottom of the slit created in the soil, trailing the tractor. Figure 3-10 shows a typical chute (or feed) blade mounted at the rear of the tractor unit.

It is important that the chute be compatible with the physical characteristics of the cable to be installed, including the clearance in the slot and the bend radius. In addition, the cable or wire should be placed with little or no tension to avoid possible damage while being pulled through the chute, including that due to the sidewall pressure that is generated by the combination of tension and curvature. The sidewall pressure may be calculated as

$$\text{sidewall pressure (lb/in.)} = \text{cable tension (lb)/chute radius (in.)}$$

Thus, minimizing the tension ensures minimal sidewall pressure, avoiding possible damage from lateral loads on the cable, and also helps prevent cable damage in the axial direction from the combination of bending and tension effects. Assuming that the cable tension is maintained at a low level, by manual or mechanized turning of the tractor-mounted

Figure 3-10. A Plow Chute Blade at the Rear of a Tractor (Courtesy of Ditch Witch).

Figure 3-11. Chute Plowing (Courtesy of Ditch Witch).

reel if necessary, placement distances with chute plowing are essentially unlimited. Depending on the size of the tractor and plow blade, it is also possible to place one or more flexible ducts using this technique, which can be used to contain the cable(s). Figure 3-11 shows a typical cable chute-plowing operation, with the cable continuously fed off a reel, mounted at the front of the tractor unit, into the plow chute blade at the rear.

The alternative procedure of pull plowing is a practical procedure for relatively short installations (e.g., hundreds of feet). It is an especially useful technique for installing new service lines in established residential areas for which it is important to minimize surface disturbance and restoration. Plows of 25 hp or less can be used for such applications. In this case, the plow's pull blade is thinner than that required to meet the

Figure 3-12. Pull Plow Blades (Courtesy of Georgia Underground Superstore).

minimal dimensions of a chute with its internal cavity for passage of the cable. Instead, a bullet of sufficient diameter to create a path for the utility line is located at the lower end of the pull blade. As a result of the thin edge of the blade, the surface disturbance is even less than that of chute plowing and is essentially invisible. Figure 3-12 shows typical pull blades.

The pull-plowing procedure is similar to that implemented for the installation of sprinkler systems in existing (finished) lawns and is minimally disruptive to the property. In this application, the plow blade pulls a flexible polyethylene water supply duct behind the bullet, typically installed within 12 in. of the surface. For utility service applications, a similar duct is installed in a similar manner, within which a service wire may be subsequently placed, with the duct providing supplementary protection. Another option is to tow in a duct with the service wire already installed within, i.e., cable-in duct.

Although it is possible to use the pull-plow operation to directly tow in the service wire behind the bullet of the plow blade without the use of duct, this procedure is not recommended. Depending on the length of the installation and the nature of the soil conditions surrounding the created cavity, the pull blade may place excessive tension on the cable or result in damage to the sheath. Such vulnerabilities would be aggravated by the dynamic impact loads resulting from the vibratory blade action. The use of the plastic duct therefore avoids potential problems during the initial cable installation stage and also provides subsequent mechanical protection, as well as future upgrade and maintenance capability. For applications in which the otherwise required or desired depth for a bare cable may not be achievable, based on the available equipment and soil conditions, the duct may be judged to represent sufficient supplemental protection to satisfy the intent of the rules (see Section 3.2.1).

Additional information regarding cable plowing is available in industry practices (Lucent 1996; RUS 2000; Telcordia 2007).

3.2.2.3 Boring. Boring methods have a long history of providing paths beneath roads, driveways, and other obstacles, representing a method of trenchless construction. In general, conventional boring methods (e.g., rod pushers or pneumatic moles) have been restricted to relatively short distances because of a lack of control in the bore path; i.e., the absence of steering capability (see Figs. 3-13 and 3-14). The use of such nonsteerable tools requires the equipment to be launched from a pit, with the boring tool initially aimed as accurately as possible. Nonetheless, such tools represent a convenient, low-cost method of installing utility lines where appropriate. These boring procedures may be used to

Figure 3-13. Rod Pusher (Courtesy of Ditch Witch).

Figure 3-14. Use of a Pneumatic Piercing Tool (Courtesy of Allied Construction Products, LLC).

pull back a bare cable or, preferably, a duct for providing a protected environment for the cable.

Recent developments, however, have added a degree of steering capability to pneumatic moles, as indicated in Fig. 3-15. In this case, the path of the tool is monitored using tracking tools similar to those used in more complex directional drilling operations.

Practical directional drilling technology for local distribution applications was introduced in the 1980s and 1990s. Such horizontal directional drilling (HDD) methods represent the state of the art in trenchless technology for cable installations. Although initially developed by the electric power and gas industries, the widest and greatest usage of HDD has been by the telephone industry in the United States.

HDD installs new pipes or utility lines belowground using a surface-mounted drill rig that launches a drill string at a shallow angle to the surface and places the pipe at a desired depth, using tracking and steering capabilities. As a form of trenchless technology, the equipment and procedures are intended to minimize surface damage, restoration requirements, and traffic disruption, with little or no interruption of existing services. Mini-horizontal directional drilling (mini-HDD) is typically used for the relatively shorter distances and smaller diameter pipes associated with local distribution lines, in comparison to maxi-horizontal directional drilling (maxi-HDD), typically used for longer distances and larger diameter pipes, such as major river crossings. Mini-HDD, sometimes referred to as guided boring, is appropriate for boring holes of up to 600 ft long

Figure 3-15. A Walkover Locator Used with a Steerable Piercing Tool (Courtesy of TT Technologies).

and placing pipes of less than 12-in. diameter at depths less than 20 ft. Maxi-HDD, sometimes referred to as directional drilling, is used for boring holes up to several thousand feet long and placing pipes of diameter 48 in. or greater at depths up to 200 ft. Midi-HDD refers to the class of directional drilling equipment and procedures that is intermediate to mini-HDD and maxi-HDD. Figure 3-16 shows a typical mini-HDD machine.

As illustrated in Fig. 3-17 for a mini-HDD operation, the drill string creates a pilot borehole in an essentially horizontal path or shallow arc,

Figure 3-16. Mini-Horizontal Directional Drilling Machine (Courtesy of Astec Industries).

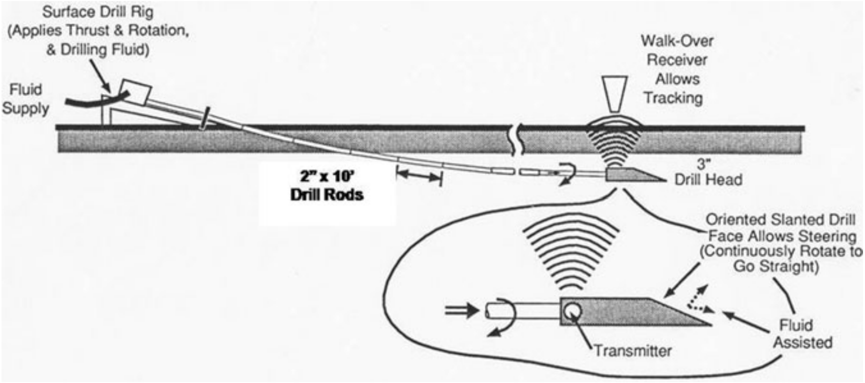

Figure 3-17. Mini-Horizontal Directional Drilling, Initial Pilot Boring Phase (Courtesy of Outside Plant Consulting Services).

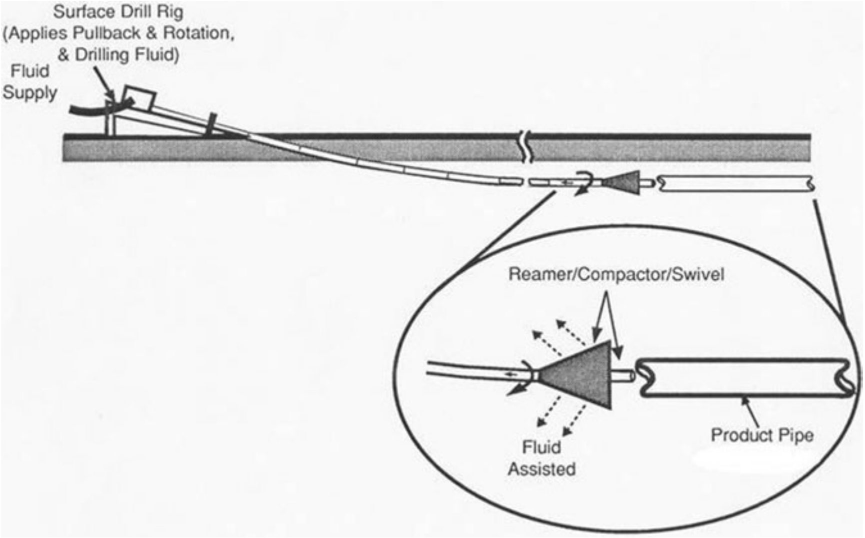

Figure 3-18. Mini-Horizontal Directional Drilling, Pullback Phase (Courtesy of Outside Plant Consulting Services).

which may subsequently be enlarged to a larger diameter during a secondary operation (Fig. 3-18), which typically includes reaming and pullback of the pipe or utility line. Tracking of the initial bore path may be accomplished by a manually operated overhead receiver or a remote tracking system. Steering is achieved by controlling the orientation of the drill head, which has a directional bias, and pushing the drill string forward with the drill head oriented in the direction desired. Continuous rotation of the drill string allows the drill head to bore a straight path. The procedure uses fluid jet cutting or mechanical cutting, or both, with a low, controlled volume of drilling fluid flow to minimize the creation of voids during the initial boring or backreaming operations. The drilling fluid helps stabilize the borehole, remove cuttings, provide lubricant for the drill string and pipe, and cool the drill head. The resultant slurry surrounds the pipe, typically filling the annulus between the pipe and the bored cavity. After a period of time, the slurry tends to thicken, resulting in a filled, stable annulus that helps support the soil and the pipe.

Mini-HDD is widely used for utility cable addition or upgrade applications. Although mini-HDD has sometimes been used to pull back a bare cable, this procedure is not recommended. Depending on the length of the installation and the nature of the soil conditions surrounding the created borehole, pulling a bare cable may result in sheath or cable damage. Thus, the use of plastic duct is again recommended, which also provides mechanical protection, as well as potential future upgrade and maintenance capability, if necessary. Because of its ability to withstand tensile loads during the pullback operation, continuous HDPE pipe, fused as necessary, has been the most common product to be installed using mini-HDD operations. Other products, however, have been successfully installed, including recently developed field-fused PVC (see Section 2.2.2.3).

Similar procedures are used for midi- and maxi-HDD operations, typically using larger and more sophisticated tracking and drilling equipment and hardware, such as “mud motors” for hard or rocky soil conditions. Maxi-HDD is used for placing pipes under large rivers or other major obstacles. Tracking information is provided remotely to the operator of the drill rig by sensors located toward the leading end of the drill string. Cutting of the pilot hole and expansion of the hole is typically accomplished with fluid jet cutting or a mud motor. A “washover” pipe is sometimes placed over the drill string to reduce torque and support the borehole. In contrast to mini-HDD installations, which are sometimes performed on a large-scale communitywide basis, maxi-HDD focuses on an individual crossing, using sophisticated technology and requiring careful planning and engineering support.

Available guides and manuals for HDD, including mini- and maxi-HDD, are available from standards-producing organizations, such as the American Society of Civil Engineers (ASCE 2005), the American Society for Testing and Materials (ASTM 2005a), and the Institute of Electrical and Electronics Engineers (IEEE 1994).

3.2.2.4 Direct-Buried Innerduct. The use of innerduct is described in Section 2.2.2.3 for placement within larger diameter conduits in underground conduit systems. This type of product, however, may be advantageously deployed to enhance the capabilities of direct-buried plant. In addition to its effective use for providing mechanical protection during pull-plowing, boring, and drilling operations, buried innerduct is a cost-effective means to allow the distribution and service wire portions of the network to be upgraded without a need for difficult and expensive digging (or trenchless) operations in the future. The duct also enhances visibility and provides some physical protection from unrelated future construction activities. In case of damage to the innerduct and internal cables or wires, the (repaired) innerduct allows convenient replacement of the damaged items. Because of the use of innerduct in such applications, the distinction between “direct-buried” and “underground conduit” systems is not always clear, as discussed in Section 2.2.1.

For distribution facilities serving residential or small business communities or other types of cable facilities, a vacant duct may be conveniently placed within the initially open trench, alongside the direct-buried original cables, in anticipation of its potential future use for a later cable addition or upgrade. In addition, initial service wires may be placed within innerducts routed from the vicinity of the distribution pedestals to the local residence or small business locations. Future required wires can later replace the original service wires, as required. It is also possible to place the original service wires directly in the trench, alongside (outside) vacant innerducts installed for future service wires. In this case, physical protection is not provided to the original service wires. Innerduct for direct-buried applications is typically constructed of high-density polyethylene, which offers the advantages of flexibility and availability in continuous lengths on a reel.[7] Although very easy to handle, conventional corrugated duct of any size is typically not appropriate for direct-buried applications. Corrugated duct in a trench tends to display relatively large undulations, complicating subsequent cable placement, and its less rugged construction may cause problems during installation or usage. The transverse ribs are also not compatible with some blown-cable installation techniques because they inhibit the air flow from applying the desired viscous drag forces to a cable and the relatively thin wall construction may not be able to withstand the operating pressure of 100 lb/in.^{2} gauge or greater (see Chapter 4). However, some recently introduced corrugated products offer a compromise between increased strength and reduced flexibility and would be acceptable for some direct-buried applications.

Prelubricated duct should be strongly considered. The type of duct and lubricant used should be recorded to avoid compatibility problems in case additional lubrication is used in the field during actual cable placement. Unless it is known that a traditional pulling method will not be used, it is recommended that the innerduct be ordered with a factory-installed, low-friction pull line to eliminate potential problems in later rodding of the duct (i.e., to install pull line) before actual cable or wire placement. The free movement of the pull line can also be used to verify initial integrity of the path, as a check on the construction process (Telcordia 2007).

A wall thickness corresponding to a dimension ratio (outer diameter divided by wall thickness) of a maximum of 13.5-to-1 (preferably 11-to-1 or less) is recommended (ASTM 2008b) for direct-buried applications. Black duct with orange (communication) or red (electric power) stripes resists ultraviolet damage and increases visibility to help avoid damage from future construction activities. Solid orange or red duct is acceptable if no portions of the duct are exposed to direct sunlight (see Section 2.2.2.3).

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[7] Alternatively, rigid PVC pipe has been routinely used for containing power service lines. The present discussion is based on the use of HDPE innerduct.

The minimum innerduct size selected should be appropriate for the type of utility in question. For example, for communication service wire applications, a minimum duct size of 1 in. (nominal inner diameter) is recommended. For communication distribution cable applications, a 1¼-in. minimum size is recommended (preferably 1½-in.). The latter size is convenient and compatible with either traditional cable-pulling or recently introduced blown-cable installation techniques (see Chapter 4). Smaller diameter duct tends to display greater undulations in trenching applications. Larger sizes (e.g. 2-in. diameter) are acceptable but are more difficult to handle, and they may allow excessive fiber-cable bending within the innerduct if a blown-cable or cable-pushing system is being used, possibly reducing cable placement distances. As a general rule, the cable size should be limited to approximately two-thirds of the duct diameter (Telcordia 2007).

The application of innerduct is an important element in pull-plowing, boring, or drilling operations. With respect to open trenching, special precautions must be observed. It may appear deceptively easy to place an innerduct into a trench, but improper procedures can lead to later problems when attempting to install a cable within the duct. Care should be taken to avoid sharp bends during the installation process that can kink the duct. Although HDPE innerduct has a high degree of inherent toughness, large rocks should be removed from the immediate vicinity of the duct. During placement, the duct should be fed off the bottom of the reel, with only one person placing the duct into the trench. It is also recommended that the duct be pulled somewhat taut during the backfill process to reduce the curvature resulting from "reel memory," especially for duct sizes less than 1½ in., but excessive tension on the innerduct should be avoided to avoid distortion or necking. In general, the supplier's guidelines should be followed with respect to minimum bend radii and other handling practices.

The use of appropriate duct plugs or caps and coupling accessories during or immediately after the innerduct placement is important to ensure the long-term integrity of the completed system. This requirement is especially significant for initially vacant innerduct for use in future upgrades. Couplers should be waterproof and, for ducts terminated belowgrade, the ends of the innerduct should be protected by watertight plugs or sealing compound to prevent entry of water or debris. Ducts terminated aboveground should have caps placed over the ends. Special plugs or caps may also be used at the ends of ducts that contain cables or wires (Fig. 2-14). Couplings should be airtight and, including the duct itself, be able to withstand an air pressure of 125 lb/in.^{2} gauge to be compatible with blown-cable installation techniques for the relatively short duration of the blown-cable installation process (ASTM 2002). If any route couplings or joints will not be accessible in the future and it is anticipated that a blown-cable installation method system may be used (see Section 4.3), it is recommended that the particular route section be subjected to a pressure test before completion of construction. With one end of the innerduct section securely plugged, the opposite end connected to an air compressor, and an auxiliary pressure gauge directly measuring the pressure in the duct, the air compressor should be turned on to pressurize the section to verify that there is minimal leakage (Telcordia 2007).

It is also recommended that the upgrade capability for service wire be occasionally verified immediately after placement of the duct, especially for routes that approach recommended upper limits for service wire length or number of route bends (see Chapter 4). This verification can be accomplished by pulling sample service wires through several vacant ducts, thereby maintaining a process control on methods and materials. As a minimum, verification should be performed after an early installation and after significant changes in materials, procedures, or installation conditions.

3.3 OPERATION AND MAINTENANCE

Operation and maintenance activities for buried plant facilities may be performed at aboveground equipment, including terminals and cabinets (Figs. 3-1 and 3-2), or possibly at belowground locations, such as buried splices or flush-mounted handholes (Fig. 2-4). In practice, however, special problems arise because of unplanned, but not uncommon, events, such as inadvertent dig-ups from unrelated construction. In such circumstances, the facilities must be physically exposed and locally repaired, or possibly replaced in their entirety. The replacement process would then be similar to that required to add a new cable in an established area, accompanied by the same associated concerns—i.e., the need to avoid further damage to other existing utilities in the vicinity and subsequent surface restoration. As described in Section 3.2, various construction methods are possible, including open-cut trenching, plowing, and boring or drilling.

3.4 ISSUES

The primary issues associated with direct-buried plant relate to the vulnerability to accidental damage because of dig-ups and the limited capacity for future cable upgrades, in case the original cables are insufficient to meet future needs or become prematurely degraded. Whereas the potential vulnerability to accidental damage may be reduced or eliminated by enforcement of proper construction procedures by other parties, including contacting the local one-call center and implementation of subsurface utility engineering procedures, the inability to conveniently add new cables is a more fundamental problem. This limitation is the motivation for the belowground cable network alternatives, as described in Chapter 5.

4

CABLE INSTALLATION METHODS IN DUCT

There are three basic methods for placing utility cables within ducts that have previously been installed in the field:

- pulling,
- pushing, and
- blown cable.

All three methods have been applied in industry, and each has its advantages, limitations, and range of application. The methods continue to evolve, with innovations based on the cable characteristics and newly introduced products. Some techniques and equipment combine elements of these categories. Additional information for placing cables in conduit is provided in *The Plastics Pipe Institute Handbook of Polyethylene Pipe* (PPI 2006).

Another alternative to placing the cable in the field after installation of the duct is the use of preinstalled cable within HDPE duct (sometimes called "cable-in-duct"). In all methods, the allowable bending radius of the cable must be observed. For example, copper cables should typically not be bent to a radius of less than 10 times the cable diameter, and fiber-optic cables should typically not be bent to a radius of less than 20 times the cable diameter when under tension or 10 times the cable diameter otherwise (Telcordia 1998; RUS 2001).

4.1 PULLING

The most obvious and direct method for installing a cable within a duct, or any cavity, is to connect a rope or pull line to the leading end of the cable, using an appropriate type of grip, and to then pull the cable into the path. Mechanized equipment is typically used because the required pull force is often significant. The force imposes a tensile load on the cable, which must not exceed its allowable tensile capability. Each cable type (e.g., electric power cable, copper pair, optical fiber, or coaxial CATV) is characterized by its own tensile strength. The strength of metallic cables is determined by the metallic conductors providing the transmission path, in combination with additional strength members, including metallic shields, if present. For fiber cables, the strength capability is provided by metallic or nonmetallic (e.g., Kevlar) strength members. The allowable strength of metallic cables therefore varies widely. In comparison, fiber-optic communication cables typically have an allowable tensile load of 600 lb, as specified in industry requirements (Telcordia 1998).

The initial step is usually to provide a pull line in the duct or cavity of interest. This step may be accomplished in various ways, including 1, preinstalling it in the duct (e.g., for continuous HDPE innerduct), 2, blowing it through with (positive or negative) low air pressure applied to a chute towing a lightweight line, used to subsequently pull in a heavier duty rope or pull line, or 3, by inserting a push rod that installs a pull line during its retraction, or which may directly pull the cable itself. One variation that avoids the need to install a pull line is the use of relatively high air pressure (e.g., 100 lb/in.^{2} gauge) with a tight-fitting "piston" to apply a tensile force to a relatively lightweight cable, accomplishing the cable placement (see Section 4.3).

Figure 4-1 shows cable-pulling equipment, and Fig. 4-2 illustrates several typical equipment configurations for pulling cable.

The primary advantage of the pulling technique is its general applicability to any type of cable. The major disadvantage relates to possible placement distances, which are limited by the tension buildup as the cable traverses the route. The tension or pull force at the leading end of the cable is required to offset the drag (resistive) forces that accumulate along the length of the cable. For the simple case of a cable resting on the bottom of a straight duct path, as illustrated in Fig. 4-3, the required tension, T, is given by

$$T = wL\mu \tag{4-1}$$

where w is the weight of the cable per unit length, L is the length of the cable within the duct, and μ is the coefficient of friction between the cable and duct surfaces. This formula is based on the commonly used Coulomb friction model, in which the local frictional drag is proportional to the local normal pressure, such as that resulting from the weight of the cable. Equation 4-1 also assumes that there is no significant restraining load at

Figure 4-1. Cable-Pulling Equipment (Courtesy of HIS Business Mfg. Co.).

the trailing end, such as a load caused by reel resistance. Such resistance, or tail load, T_0, would result in an equivalent increased load at the leading end.

The Coulomb proportionality factor, the coefficient of friction, μ, depends on the inherent mutual surface characteristics. The coefficient of friction may be reduced to more desirable levels by surface treatment, including the addition of lubricants. Such lubricants may be added to the duct immediately before cable installation, although various (HDPE) products are available with lubricant integrated into the plastic compound, or extruded as an additional interior lining. Figure 4-4 shows an externally added lubricant for facilitating the cable installation process.

Based on Eq. 4-1, a lightweight fiber or coaxial cable, with the typically low-friction combination of a polyethylene cable jacket and an HDPE duct, would be predicted to require minimal pull loads, corresponding to relatively large placement distances. For example, a fiber communication

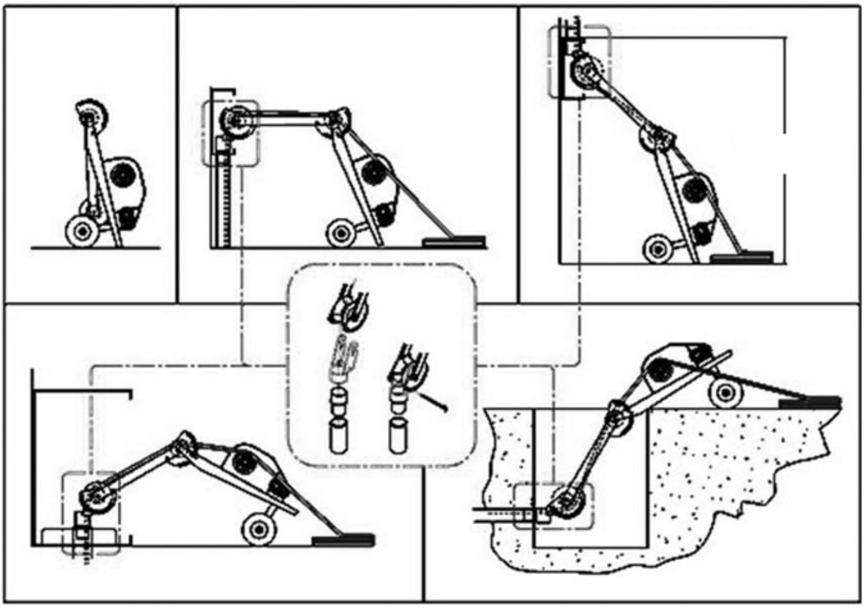

Figure 4-2. Typical Cable-Pulling Setups (Courtesy of HIS Business Mfg. Co.).

cable weighing approximately 0.15 lb/ft, with a coefficient of friction, without lubrication, of 0.35 (Telcordia 1995) when pulled into an HDPE duct, would be predicted by Eq. 4-1 to require only 0.0525 lb/ft. The required tensile strength of 600 lb would therefore suggest potential placement distances of approximately 11,000–12,000 ft—or more than 2 miles. Such predictions greatly overestimate the practical placement distances of considerably less than a mile, on the order of 1,000 ft, and they occur essentially because of effects not considered in the simplified model of Fig. 4-3 and Eq. 4-1.

To better reflect reality, a more complete model must be considered, which includes the aggravating effect of tension at duct bends and curvature. Figure 4-5 illustrates a cable, under tension, pulled around a discrete (local) bend. The tension vectors on the cable, acting at the opposite ends of the bend, are not collinear and therefore result in reaction pressure along the curved surface because the cable is effectively pulled snug against the inside of the bend. This pressure results in increased drag and may be shown to result in a greater tension at the exit of the bend. Thus, for a tension, or tail load, T_0, at the entry, the tension at the exit, or head tension T_1, is given by

$$T_1 = T_0 e^{\mu\theta} \tag{4-2}$$

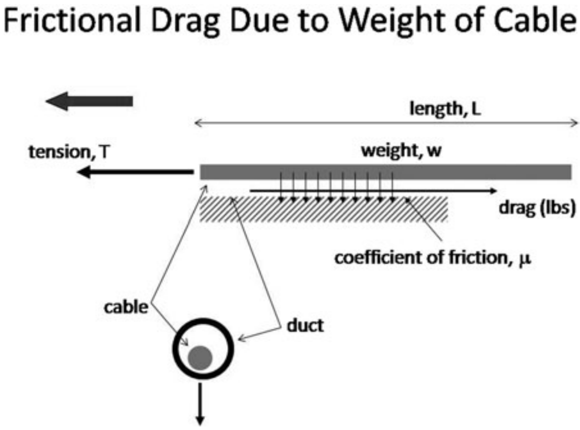

Figure 4-3. Basic Cable-Pulling Mechanism (for a Straight Path) (Courtesy of Outside Plant Consulting Services).

Figure 4-4. Cable Lubricant (Courtesy of American Polywater Corporation).

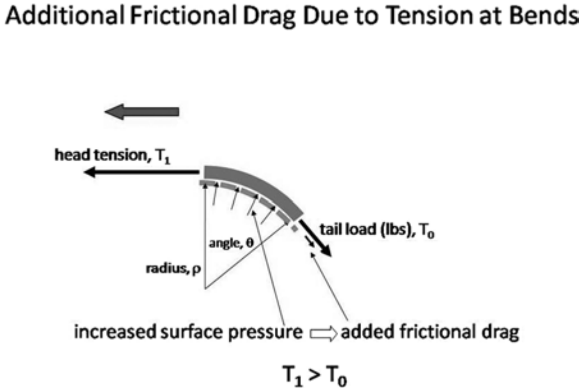

Figure 4-5. Increased Tension at a Discrete Bend (Courtesy of Outside Plant Consulting Services).

where the angle θ is expressed in radians. The exponential term has great significance, effectively acting as a cumulative, compounding effect at discrete bends along the duct path, which is independent of the cable weight, cable stiffness,[1] path radius of curvature, and direction of curvature. This phenomenon is sometimes referred to as the "capstan effect" and is the basis of the capstan winch used on boats to secure the boat to the dock. In this implementation, a rotating drum (capstan) is used to develop a high tension at one end by means of a relatively low tension at the opposite end, based on the cumulative drag around the several loops of rope on the drum (see Fig. 4-6).

For a path with distributed curvature, such as a gradual bend in a horizontal plane, the effect of cable weight plus curvature may be shown to result in the following formula for the tension at the leading end:

$$T_1 = T_0 \cosh(\mu L/\rho) + [T_0^2 + (w\rho)^2]^{1/2} \sinh(\mu L/\rho) \qquad (4\text{-}3)$$

where ρ is the radius of curvature of the horizontal bend. The mathematical cosh and sinh functions contain exponential terms similar to that of Eq. 4-2. For large radii of curvature or high values of initial tension T_0, Eq. 4-3 reduces to Eq. 4-1 or 4-2, respectively. The original analysis for this technology was performed within the power industry and also considered bends in vertical planes for which various equations were developed, depending on the quadrant of the curve (Buller 1949; Rifenberg 1953). The

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[1] Cable stiffness is an additional aggravating factor but is not directly considered in the current discussion.

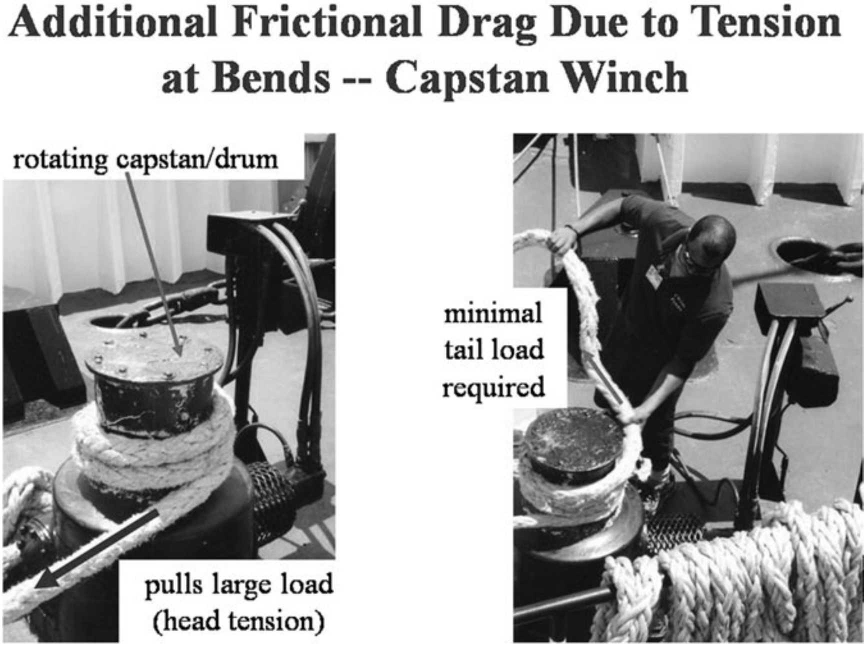

Figure 4-6. Illustration of the Capstan Effect (Courtesy of Outside Plant Consulting Services).

corresponding formulae are contained in *The Plastics Pipe Institute Handbook of Polyethylene Pipe* (PPI 2006). This theory was subsequently applied to communication cables, including more recently developed fiber-optic cable applications (Griffioen 1993).

For practical applications, nominally "straight" rigid conduit paths actually display a small degree of curvature because of some degree of flexibility and corresponding lack of straightness in the installed plastic pipe, combined with possible undulations and spiraling of innerduct placed within the conduit for the subsequent placement of fiber cable. Based on investigations at Bell Telephone Laboratories, an effective curvature of approximately 160° per 1,000 ft—i.e., almost one 90° bend per 500 ft of duct path—may be assumed, which corresponds to an effective radius of curvature ρ of approximately 360 ft.[2] Furthermore, although no tail load is deliberately applied to the cable, an effective initial tension, T_0, corresponding to the weight of 127 ft of (fiber) cable may be assumed. This

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[2] Path curvature (radians per unit distance) is equal to the reciprocal of the radius of curvature ρ. One radian equals 57.3°.

assumption is also based on empirical results obtained at Bell Telephone Laboratories, and it may be considered to occur because of a combination of effects, such as coil memory and cable stiffness, resulting in increased reactive pressure at the beginning of the duct path. (A recommended procedure is to manually or mechanically turn the feeder cable reel to avoid or minimize any additional tail load.) In addition to the finite effective curvature along the nominally straight route, there are often discrete bends at sweeps into manholes or other access points, as well as at deliberate planar bends along the route. The combination of all these effects, which may be quantified via sequential application of Eqs. 4-2 and 4-3, results in greatly reduced pulling lengths.

For directly buried flexible HDPE duct (innerduct), the effective curvature would typically be significantly greater than that experienced within the relatively rigid conduit path described earlier (in Section 2.2.2.3), depending on the innerduct construction, size, and method of burial. Trenched installations tend to display the largest effective curvature, with plowed and directionally drilled installations displaying less curvature. Trenched duct may reduce placement distances to much less than 1,000 ft.

In general, the primary limitation of the traditional pulling method for installing cables within pipes is the rapid tension buildup associated with the significant cumulative compounding effects at route bends and path curvature. The need to provide or install a pull line represents an additional inconvenience. The use of air pressure and a piston does avoid the need for a separately installed pull line, but the technique is further limited by the relatively low pull force that may be safely generated by the air compressor (typically 100 lb/in.^{2} gauge) (see Section 4.3).

4.2 PUSHING

Pushing a cable from the near (reel location) end offers some advantages relative to the traditional pulling technique, including elimination of the need for a pull line. Nonetheless, the procedure inherently suffers from similar limitations in potential placement distances. In particular, a capstan effect resulting from the axial forces pushing the cable snugly against the *outside* of the bend also leads to escalating friction forces, with placement distances again severely limited by the presence of duct bends and path curvature. In general, equations analogous to those in Section 4.1 are applicable, resulting in the exponential buildup of required push force because of inevitable path curvature. However, the combination of a conventional cable puller at one end of a duct and a cable pusher at the opposite end can significantly increase the cable placement distances. Figure 4-7 illustrates cable-pushing equipment.

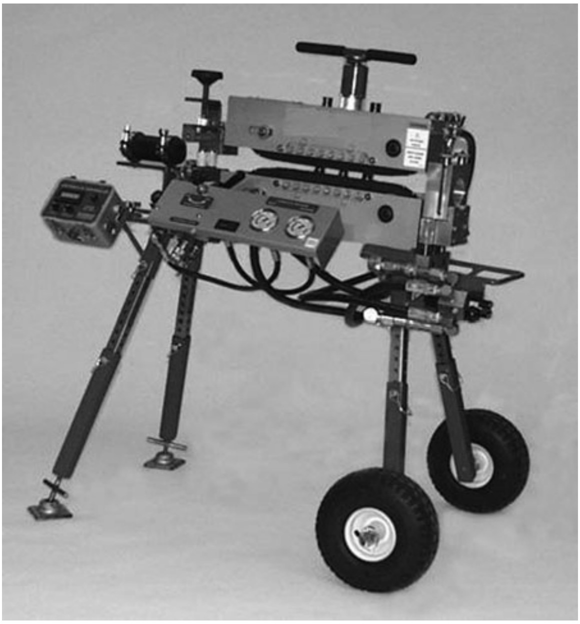


Figure 4-7. Cable-Pushing Equipment (Courtesy of A-D Technologies).

In the pushing method, a longitudinal force is applied to the cable, typically by drive wheels or tractor treads acting laterally on the cable sheath, resulting in an axial compressive load on the cable. Unlike the tensile load on a cable, which is generally characterized by industry-specified or reasonably well-defined limits, such as those based on the capacity of the metallic or tensile strength components, allowable axial compressive loads on cables are less well defined. In many cases, the allowable compressive loads must be empirically determined and corresponding forces monitored by the installation equipment. A typical failure mode of cables under axial compression includes buckling and kinking. The possibility of such a failure is a function of the magnitude of the required push force, the bending stiffness of the cable, and the clearance in the duct. The tendency to buckle a cable increases with push force, lower stiffness, and increased clearance. Pushers are particularly effective for placing primary power supply cables because of their high stiffness characteristics.

4.3 BLOWN CABLE

In general, there are two categories of blown-cable methods: “low air-speed” blown-cable (LASB) and “high air-speed” blown-cable (HASB). In both cases, an air compressor is used to provide air pressure (e.g., 100 lb/in.^{2} gauge) to the duct in which the cable will be installed. There is no need for a pull line to be preinstalled in the duct. Although originally designed to install lightweight fiber-optic cables, both techniques have been successfully applied to other types of utility cables, including relatively large power cables, at reduced placement distances. Both methods are typically applied to place cables within innerduct, for which any couplings must meet the air pressure requirements described in Sections 2.2.2.3 and 3.2.2.4.

For the LASB method, a dart or inflatable chute, acting as a piston, is attached to the leading (free) end of the cable, which applies a tensile load corresponding to the applied pressure level and the area of the piston. A relatively low capacity air compressor is sufficient because the piston or chute is designed to effectively capture the air, limiting the flow rate to approximately that corresponding to the cable placement speed. A cable pusher has also been added to LASB-type equipment, resulting in an efficient system that simultaneously uses both pulling and pushing forces applied to the cable to increase placement distances well beyond those achievable with either of these individual impetus mechanisms and under significantly less tensile stress than that experienced in traditional pulling methods. The LASB method is adaptable to adding a cable to an occupied duct, which may otherwise have additional capacity through the use of a Y-type adapter. Figure 4-8

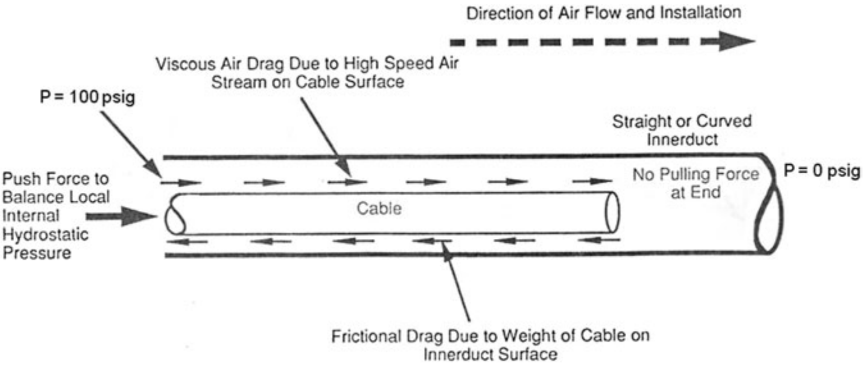
Figure 4-8. Commercially Available Low Air-Speed Blown-Cable Equipment, Including an Integral Cable Pusher (Courtesy of A-D Technologies).

illustrates commercially available LASB cable placement equipment, including an integral cable pusher.

The HASB method eliminates the chute present in the LASB method. Although this method may appear to be disadvantageous because of the loss of the pull force at the leading end of the cable, it introduces an interesting beneficial effect because of the viscous drag effects imposed on the cable associated with the high rate of airflow out of the far end of the duct. This technique assumes that an air compressor of sufficient capacity is used to maintain the desired pressure (100 lb/in.^{2} gauge) at the cable entry end in the presence of the open duct at the far end. The principle of operation is illustrated in Fig. 4-9, which shows the distributed viscous air drag forces acting along the length of the cable in the direction of the desired cable placement. These forces tend to balance the resistive frictional drag forces opposing the cable movement along the duct. Based on the simplifying assumption that the air mass is in equilibrium within the duct subject to the pressure difference between the near end and the far end (atmospheric pressure = 0 lb/in.^{2} gauge), and the equally distributed viscous drag forces acting along the exposed lateral surfaces of the cable and duct, the beneficial viscous drag effect, F_{viscous}, may be estimated as

$$F_{\text{viscous}} = P\pi d_{\text{cable}}\,(d_{\text{duct}} - d_{\text{cable}})/4 \tag{4-4}$$

where P is the applied pressure, d_{cable} is the diameter of the cable, and d_{duct} is the inner diameter of the duct.



Note: Duct Shown Straight for Convenience; May Also be Curved Path

Figure 4-9. High Air-Speed Blown-Cable Principle of Operation (Courtesy of Outside Plant Consulting Services).

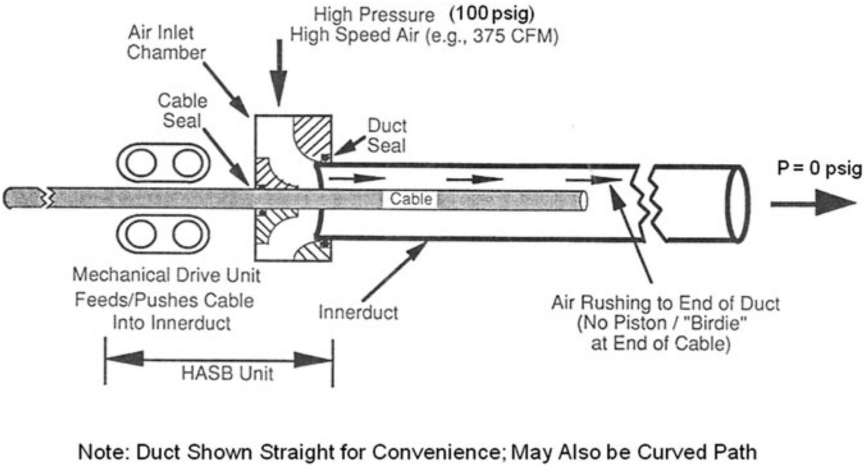


Figure 4-10. High Air-Speed Blown-Cable System (Courtesy of Outside Plant Consulting Services).

In addition, there is a need to impose an axial push force at the entry point of the cable into the duct to balance the internal hydrostatic pressure acting on the free end of the cable; the latter pressure tends to resist the insertion of the cable into the high-pressure area, especially at the beginning of the installation, before a significant length of cable has been installed in the duct. This push force is equal to the entry pressure (100 lb/in.^{2} gauge) multiplied by the cross-sectional area of the cable; e.g., for a cable of ½-in.^{2} cross section, a force of 50 lb must be initially applied. Thus, a cable pusher is a basic component of the HASB system, as illustrated in Fig. 4-10. The balancing push force combines with the viscous drag force of Eq. 4-4, resulting in a net basic insertion force of

$$F_{\text{viscous}} = P\pi d_{\text{cable}}\, d_{\text{duct}}/4 \tag{4-5}$$

Equation 4-5 represents the net force available to overcome the overall frictional drag represented by Eq. 4-1.

This force is effectively locally distributed along the length of the cable, which may be considered to offset locally the frictional drag force acting at the cable and duct surfaces. Tension is not required to accomplish cable placement and therefore does not tend to develop, accumulate, or escalate along the route, including at route bends. In principle, placement distances would be independent of the presence of route bends or curvature,

Figure 4-11. Cable Lubricant for Blown-Cable Installation (Courtesy of American Polywater Corporation).

which is a major advantage, in addition to relaxing the tensile load requirement on fiber cable products. Thus, although the corresponding basic insertion force level of Eq. 4-5 may not be as large as the typical tensile capability of fiber cables, the potential placement distances are often greater. For example, considering the cable weight and frictional characteristics of Section 4.1, the high-speed airflow, in combination with the relatively low applied push force, predicts placement distances significantly exceeding 1,000 ft, independent of the degree of path curvature or presence of route bends.

However, an important objective of HASB methods is to efficiently use the cable pusher to supply additional thrust as a means of overcoming various degradations not accounted for in the simple model described above, as well as to maximize actual placement distances. As a result of such additional thrust, consistent with the axial compressive load strength discussed in Section 4.2 and significantly reduced frictional characteristics associated with the efficient use of appropriate lubricant (Fig. 4-11), depending on the route geometry, placement distances of a mile or greater are routinely accomplished with lightweight fiber cables. The insertion of a cable into an occupied duct is also possible.

In general, the supplier of the HASB system should be consulted for a prediction of cable placement distance based on the relevant parameters for each particular installation. The supplier may also provide

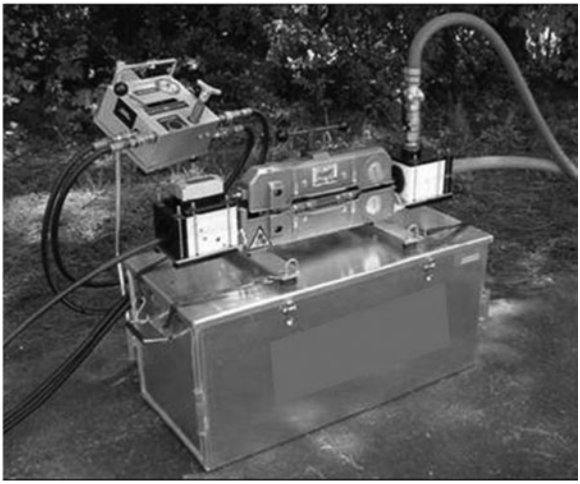


Figure 4-12. Commercially Available High Air-Speed Blown-Cable Equipment, Including an Integral Cable Pusher (Courtesy of Sherman & Reilly).

information regarding the required air compressor rating (in cubic feet per minute). Although HASB placement distances are relatively insensitive to bends, effects from cable stiffness, coil memory, and route curvature may have a secondary degrading effect, depending on the specific installation, and can be reflected in some prediction techniques (Griffioen 1993). Figure 4-12 illustrates commercially available HASB cable placement equipment.

5

HYBRID BELOWGROUND CABLE NETWORKS

5.1 BACKGROUND

The two major categories of belowground placement for utility cables are described in Chapters 2 and 3. Each method has its advantages and disadvantages. Formal underground conduit systems offer convenient upgrade capability but at a high expense. Direct-buried construction is relatively inexpensive, but corresponding conventional construction procedures are not compatible with future cable additions or replacements, should the need arise. These disadvantages or limitations are the motivation for the development of "hybrid" systems, which combine the advantages of both methods of construction and are designated as belowground cable networks (BCNs).

The direct-buried philosophy is based on the assumption that the initially placed cables are sized and designed to meet the ultimate needs of the community, as foreseen at the time of initial placement. In reality, the need to add new cables is not infrequent. New technologies (e.g., fiber optics), larger than anticipated transmission requirements (e.g., for electric power supply), or prematurely degraded or damaged cables then require difficult or expensive construction methods to accomplish the required additions. The rapid growth of trenchless technology, including directional drilling (see Section 3.2.2.3), has occurred in large part because of the need for such upgrades. Although such trenchless methods are extremely valuable techniques, it would obviously be more convenient, and considerably less expensive and problematic, if the new cables could be inserted into an existing duct or path already in the ground, similar to an underground conduit network capability, although of a less expensive architecture. In an attempt to provide some degree of upgrade capability, some utilities or organizations have individually included a vacant buried duct (e.g., continuous polyethylene duct), or equivalent, in the initial trench, to be available at a later date, as the need may arise. However, such practices are not consistently applied within the individual utilities or efficiently and cost-effectively shared among the other residents of the trench, nor are they optimized with respect to their long-term use and asset management.

The belowground cable network (BCN) systems are intended to represent cost-effective, space-efficient overall solutions for direct-buried utility (e.g., electric power, telephone, and CATV) or miscellaneous communication lines. Such systems provide an opportunity for conveniently and safely accomplishing cable upgrades at a relatively low initial incremental cost to the utilities and their customers, as well as resulting in long-term savings on a life-cycle basis. A BCN system would benefit communities and roads of various types, including those serving homes and small businesses, as well as highways. Although Chapter 5 focuses on one type of BCN, other designs or architectures may possibly be developed to accomplish similar objectives. The issues addressed in the development of the currently described network may be useful in helping implement other BCNs.

5.2 DESCRIPTION OF THE EXAMPLE BCN

Figure 5-1 illustrates one type of BCN, representing an integrated system of ducts and handholes. An important feature of this BCN is the use of cost-effective joint (shared) construction practices, consistent with optimized utility practices. Thus, a single main trench along the right of way would be used for several utilities or organizations, as well as a single service trench to each home (or small business) for residential applications, as appropriate. The size and type of the indicated, initially installed (direct-buried) distribution cables would be selected based on the conventional engineering rules used by the utilities in their initial attempt to meet present and future (ultimate) anticipated needs. Thus, the BCN upgrade capability would only be used to meet unanticipated needs that nonetheless often arise because of the desire to introduce new technologies, increase capacities, or replace degraded cables and wires. The upgrade capability of the BCN would likely not be sufficient if the utilities or other organizations deliberately reduced their initial cable capacities based on expected future usage of the BCN capabilities.

The initially installed distribution cables would be placed in the trench to be directly buried in the soil using current rules and practices and would be terminated at the required equipment or (above or belowground) terminals. For residential or small business applications, the

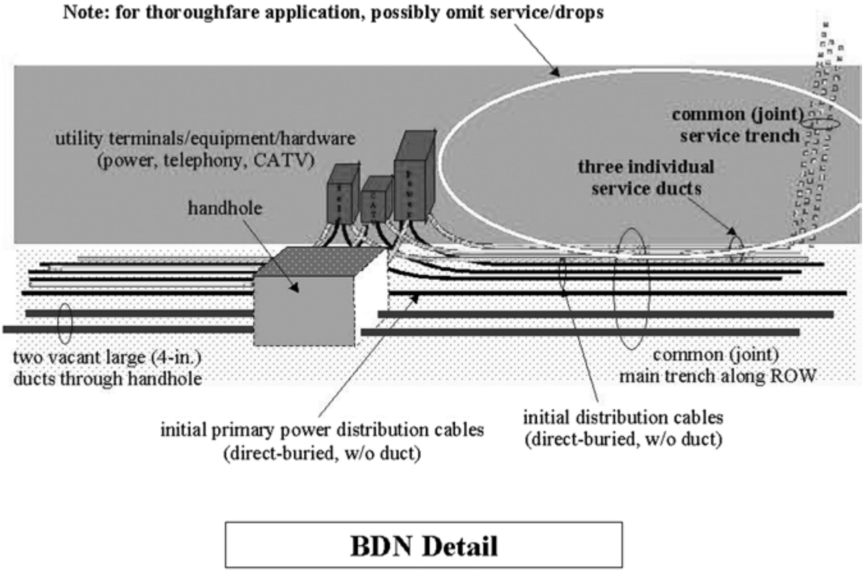


Figure 5-1. Example BCN Architecture (Courtesy of Outside Plant Consulting Services).

initially required individual communication and electric power (120–240 V) service wires or drops would be placed within small-diameter (e.g., 1–3-in.) service ducts and routed to the individual unit from the adjacent pedestal terminals or equipment mounted at the right of way, following a path such as that indicated in Fig. 5-1. The service wires would therefore benefit from the inherent mechanical protection and may subsequently be used to pull in any future replacement wires. In general, separate service ducts would be required for each of the three utilities (i.e., telephone, CATV or cable, and electric power).

Two initially vacant, relatively large diameter (e.g., 4–6-in.) main duct paths would be routed along the right of way in the same main trench as the direct-buried distribution cables, but otherwise they would have no initial connections to the terminals, equipment, or hardware. One duct could, for example, be used for future electric power upgrades or maintenance, and the other duct could be used for communication (telephone or CATV), although the actual final implementation may vary, based on the actual needs. Thus, if the demand for new communication cables requires the use of both ducts, that is an option. Conversely, a power upgrade or maintenance activity may require the use of both ducts, especially if it involves both secondary (120–240 V) and primary (e.g., 13.8 kV) cables. The current architecture, which is made of only two main ducts, is based on the probability that not all utilities would require an upgrade in the foreseeable future and that such duct capacity would therefore be sufficient for practical cable upgrade or replacement needs. The BCN therefore takes advantage of statistical sharing of a limited number of ducts in comparison to the inefficiency associated with restricted allocation of conduits to particular utilities (see Section 2.2.2.1). A reasonable joint-usage agreement among the utilities would allow for equitable cost sharing based on the actual future occupancy of the ducts.

The main distribution ducts may be of high-density polyethylene or commonly used rigid polyvinyl chloride. The 4-in. (or 5- or 6-in., if necessary) size is sufficiently large to practically accommodate most utility cables and allows the option of further subdivision into several paths for typically smaller diameter communication cables by the subsequent installation of several innerducts, or textile fabric cells, at a future date (see Section 2.2.2.3).

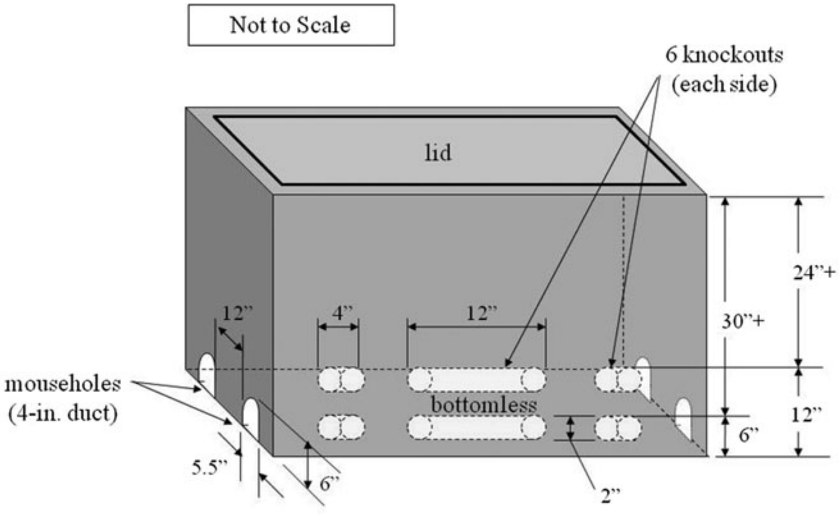
At the time of future upgrade or replacement of any of the facilities, new distribution cable may be readily installed into one of the large distribution ducts and temporarily accessed at the handhole for routing to the adjacent existing or future replaced terminal or equipment, as appropriate. The connection to the equipment or hardware may be accomplished by local digging, using safe digging methods (e.g., hand tools or air or water vacuum tools) that require only minimal excavation. For a residential or small business application, new service drops may be placed using the initially installed duct paths to the homes or small businesses. Thus, the ducts serve as a means of placing new cables or wires without requiring major construction.

5.2.1 Handhole Configuration and Implementation

A flush-mounted belowground utility box (or "handhole") is an essential element in this example BCN. The BCN uses a joint-use (shared) handhole to serve the needs of all participating utilities or organizations. For residential (or small business) applications, a handhole may be located with each group of aboveground service pedestal terminals. For nonresidential applications (e.g., on highways or thoroughfares), the handholes would be located adjacent to required equipment or terminals or in other convenient locations to facilitate cable installation or accomplish a splice. Figure 5-2 illustrates a typical handhole design as currently envisioned for the BCN. The bottomless feature allows water drainage, as well as the possible option of routing cables to the adjacent pedestals through the floor. More important, the bottomless design allows the handhole to be readily placed directly over the two previously installed main distribution ducts routed along the right of way in the trench with minimal effort. Two collinear "mouseholes" located at opposite ends capture each main duct passing through the handhole.

These design features also allow the possibility of inserting an additional handhole, at any time in the future, at an intermediate point along the route with minimal disruption and construction, including at locations where it may be decided to cost-effectively omit a handhole during the initial construction stage. A small pit would be required later to expose the two main distribution ducts, over which the handhole may be readily placed.

Knockout ports or slots are provided at the sides of the handhole to facilitate future routing of cables to the various adjacent equipment or hardware terminals (existing or replaced), as required. Elongated slots, as indicated in Fig. 5-2, provide additional flexibility in the handling of communication cables (with the sheath locally removed), as an alternative to passing the free end of the cable through the handhole port to the adjacent terminal, and back into the handhole to continue along the main distribution duct path. Both methods would avoid the need to cut the cable across its entire cross-section, which would require undesirable splicing of all the copper pairs or fibers within the cable, when access to only a limited number of pairs or fibers is necessary.



(Nominal 2 ft. wide x 3 ft. long x 36+ inches deep)

Figure 5-2. Typical Handhole for Example BCN Architecture (Courtesy of Outside Plant Consulting Services).

To further simplify the installation process, two possible alternatives for interfacing the main distribution ducts at the handhole may be deployed. For example, the duct may be cut at the entrance and exit of the handhole at the time of initial installation and plugged or sealed to prevent intrusion by water or debris to allow successful implementation in the future, when needed. The second alternative is to simply express the duct through the handhole, eliminating the need to locally cut the duct at the handhole and seal the openings, thereby reducing initial installation labor and material costs. For the latter option, the duct may be cut and accessed in the future, as required; this method is consistent with the later addition of intermediate handholes.

In general, the handhole does not represent an access point for routine maintenance operations. The handhole is used only in the rare event of an upgrade and does not therefore contain any terminals or splices, only cables being routed to their nearby equipment or terminal destination. The handhole cover would be replaced and secured or locked until the event of another upgrade, presumably by a different utility. Thus, the issue of vandalism, public safety, or the safety of communication employees working in the vicinity of active power facilities should not arise.

5.2.2 BCN Implementation and Installation Alternatives

Although the described BCN was originally envisioned to be jointly owned and operated by the several (e.g., electric power, telephone, and CATV) utilities initially sharing a single trench, with the two spare main ducts assigned as necessary to meet future needs of any of the partners, an alternate approach would be for a department of transportation or other road or government authority to own the two vacant ducts and to sell or lease them to a particular utility as necessary. Also, joint usage (sharing) of the BCN by only communication carriers (e.g., telephone or CATV)—including possible intelligent transportation system (ITS) cables—represents a useful subset of utilities and would provide similar benefits without some of the complications inherent in sharing the upgrade capabilities with electric power facilities. Indeed, the proliferation of communication service providers in many areas strains the infrastructure of these communities, which would derive major benefits from the deployment of the BCN. This alternative could include the case of a trench containing only communication cables, as well as a trench including power facilities deliberately separated from (e.g., 12 in. below) communication cables, for which the upgrade capabilities would be restricted to future communication needs. The issues involved with electric power sharing the same trench and BCN system as communication utilities include the need to satisfy additional safety rules, potential electrical signal interference imposed on communication lines by proximity to power cables (or vice versa),[1] and the need to coordinate the trench construction among the various residents. There are therefore various alternative designs for implementing the described BCN concept to accomplish the desired objectives of providing a cost-effective, upgradable method for buried construction. Several such alternatives are described here. It is anticipated that additional variations for deployment of the illustrated BCN concept will evolve as its usage expands.

5.2.2.1 Communication Trench, Including the BCN. Figure 5-3 illustrates the installation of the BCN in a trench restricted to communication cables only. This is the simplest implementation, for which the two vacant ducts are available for the placement of additional cables in the future, as necessary, for the benefit of the initial service providers, as well as possibly for additional communication companies wishing to provide such services in the future.

For applications involving communication utilities only, there are no special requirements regarding physical separation of communication

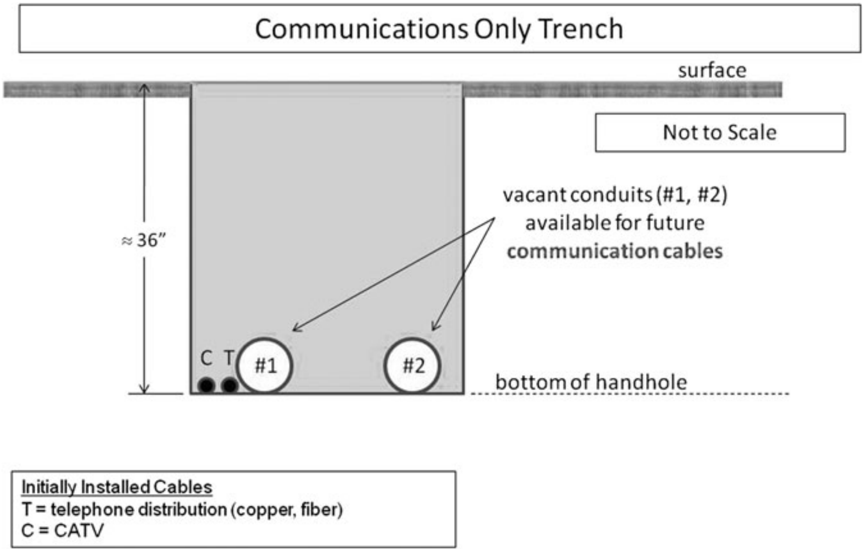


Figure 5-3. Communication Trench, Including the Example BCN (Trench Backfill Details Not Shown; see Section 3.2.2.1).

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[1] The NESC rules address potential safety issues and do not provide details regarding possible "supply-line influence and communication-line susceptiveness." The NESC recommends "cooperative procedures . . . to minimize steady-state voltages induced from proximate facilities."

cables (see Sections 2.2.1 and 3.2.1). Indeed, several communication utilities can place their cables within a common duct, as long as the parties concur. Thus, both of the main distribution ducts would be available to be shared by several cables, installed simultaneously, or—more likely—placed at different times, using smaller innerduct or subduct paths within the larger main duct, for more efficient usage of the available space.

Although, as described above, the handhole is generally not to be used to contain equipment or splices, an exception would correspond to the extreme case of a single owner or user of the trench and BCN. In such instances, the handhole may be used in a more conventional manner to house such items, with the understanding that the upgrade capabilities of the BCN would be used exclusively for the benefit of the single initial occupant.

5.2.2.2 Joint-Use Trench, Including the BCN for Communication Utilities. Figure 5-4 illustrates the installation of the BCN in a joint-use trench (i.e., communication and power cables) for which the BCN ducts are intended for use for future communication cables only. This design is

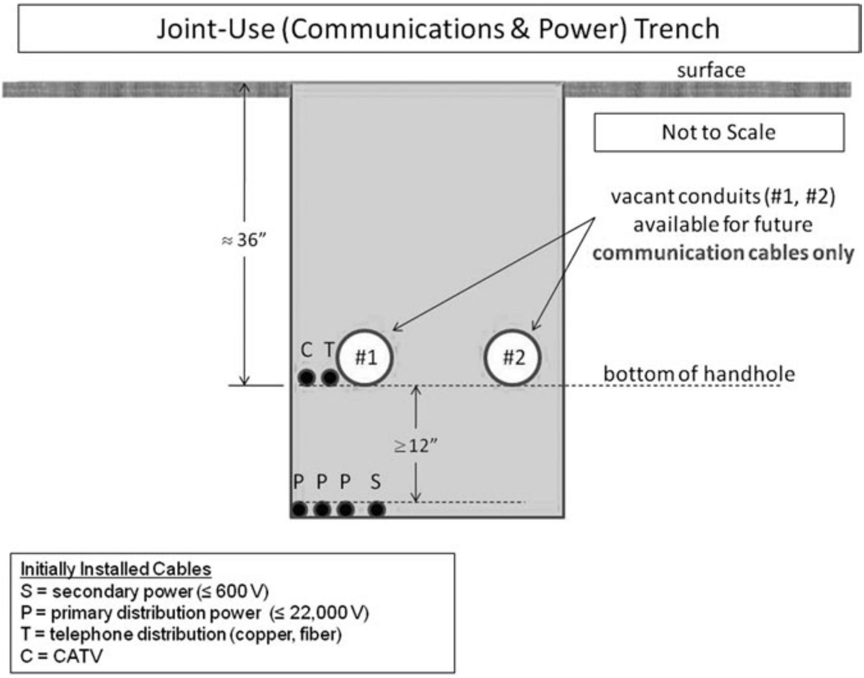

Figure 5-4. Joint-Use Trench, Including the Example BCN for Communication Only (Trench Backfill Details Not Shown; see Section 3.2.2.1).

a straightforward extension of current joint-use practices, but it provides upgrade capability for the benefit of the initial communication service providers, as well as for additional communication companies wishing to provide such services in the future. In general, the installation of additional communication cables is more likely than that of power cables. Nonetheless, there are significant benefits for the power company because this utility would be protected against damage from future construction by communication companies which, in the absence of the BCN, would otherwise attempt to install new cables using aggressive construction methods (e.g., open-cut trenching, boring, or drilling). The decision to use, or not use, the available BCN ducts for subsequent power may be postponed to a future date, at which time the procedures outlined in Section 5.2.2.3 would be relevant.

For this implementation, the initially installed cables indicated in Fig. 5-4 are placed similar to those shown in Fig. 3-6, with a deliberate vertical separation of 12 in. minimum between power and communication lines. The bottom of the handhole, as well as vacant main distribution ducts, is installed at the level of the communication cables.

Figure 5-5 represents a variation to that illustrated in Fig. 5-4, for which the initial power cables are placed within separate ducts at the bottom of the joint-use trench, consistent with some recent practices in the power industry. Such ducts may be useful for avoiding future digging or construction for meeting power supply needs.

5.2.2.3 Joint-Use Trench, Including the BCN for Communication and Power. Figure 5-6 illustrates the implementation of the BCN for future use by communication and power utilities, as originally envisioned, as representing the most cost-effective option, for which the initially placed power ducts of Fig. 5-5 may be eliminated, if desired. In this case, the use of slightly larger vacant ducts (e.g., 6 in.) may be considered advantageous, though at a correspondingly greater material cost. Also, the handhole must be modified accordingly (i.e., for larger mouseholes).

The depths of the initially buried communication and power cables indicated in Fig. 5-6 are consistent with the 24- and 30-in. minimums, respectively, specified in the NESC and Telcordia requirements described in Section 3.2 (IEEE 2007; Telcordia 2007). When a future cable is placed within one of the ducts and routed out the side of the handhole to an adjacent equipment terminal, a 24- or 30-in. depth of cover may be maintained, depending on the selected port(s) (Fig. 5-2).

For this implementation, the two vacant ducts of the BCN would be available for the needs of any of the resident utilities. Communication cables may be placed within either duct No. 1 or duct No. 2 (Fig. 5-6). To maximize the efficiency of duct use, communication cables should share the same duct to as large a degree as possible, via the use of subducts.

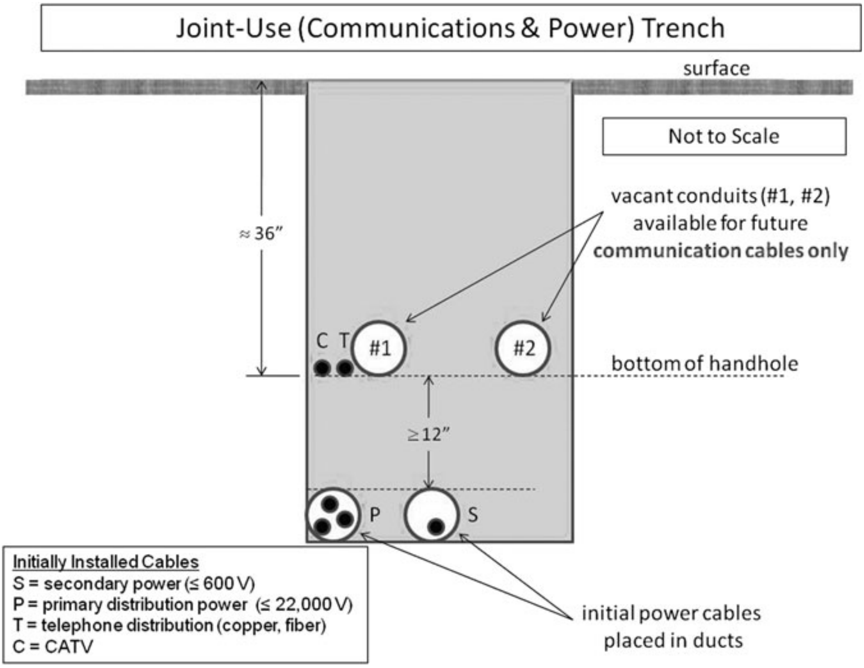

Figure 5-5. Joint-Use Trench, Including the Example BCN for Communication Only with Initial Power Cables in Ducts (Trench Backfill Details Not Shown; see Section 3.2.2.1).

Based on NESC safety rules, power cables and communication cables cannot share the same duct, unless they are operated and maintained by the same utility (IEEE 2007). Therefore, in general, subsequent power and communication cables would be placed in separate BCN ducts. Nonetheless, this method may result in future power cables being relatively close (i.e., less than the nominal desired 12-in. separation) to the initial direct-buried communication cables or to future communication cables placed in the opposite duct, as discussed below.

If a power cable is placed within duct No. 2 on the opposite side of the trench from the initial direct-buried communication cables, and the minimum 12-in. indicated spacing between the duct surfaces is maintained along the entire route, the communication and power cables are generally considered to be adequately separated. However, if the 12-in. spacing between the duct surfaces is not maintained along the entire path or if a power cable is placed within duct No. 1 adjacent to the communication cables, it will generally be necessary to follow special procedures, which depend on the voltages involved. For example, for secondary

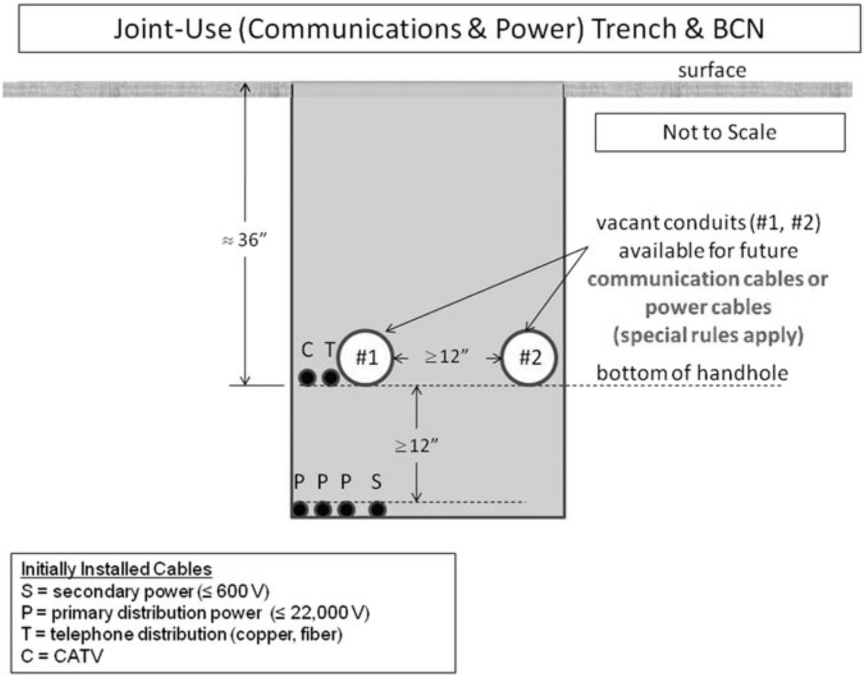

Figure 5-6. Joint-Use Trench, Including the Example BCN for Communication and Power Supply (Trench Backfill Details Not Shown; see Section 3.2.2.1).

power (e.g., 120–240-V customer usage levels), the separation may be random, i.e., no deliberate separation (less than 12 in.), providing that both parties agree and that the communication and power cables are appropriately bonded together (e.g., at intervals not exceeding 1,000 ft). For primary power levels, on the high-voltage side of the transformers, additional rules for random separation (see Section 3.2.1) must be satisfied. In such cases, the supply voltages must not exceed 22,000 V to ground (for a grounded supply system)[2] and the cable neutrals must be grounded a minimum of eight times per mile, twice as much as may otherwise be required, i.e., four times per mile.[3] (The NESC provides additional details

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[2] For an ungrounded supply system, the supply voltages must not exceed 5,300 V phase to phase.

[3] An alternative to the more frequent grounding interval would include the burial of a separate bare conductor in contact with the earth adjacent to a duct that may contain a (future) power cable. It may therefore be advantageous to place such a conductor during the installation of the BCN system, if such applications are considered.

for random separation between communication and supply cables (IEEE 2007).)

For mixed applications in which communication cables are placed within one duct and power supply cables are in the other duct, both cables may be close, such as within the handhole, possibly again requiring adherence to the rules for random separation. It is also recognized that primary power cables tend to be relatively large, stiff cables and, depending on the particular size and placement technique, may not be able to be conveniently handled within the confines of the proposed BCN handholes or routed out the lateral portals. In this case, the cables in the BCN duct may be intercepted external to a particular handhole, before duct entry or exit, allowing greater flexibility in the handling and local bending of the bulky cables, and possibly avoiding proximity to communication cables within that handhole.

Such rules and procedures for this implementation obviously represent an inconvenience in some cases. Nonetheless, this method is often a more desirable alternative than having to resort to typical trenching or trenchless construction, considering overall cost, safety, and other construction-related issues. A relatively simple option is to limit the BCN capability for power upgrades to secondary (low-voltage) power lines, which are more flexible with respect to their handling characteristics and safety-related rules. Furthermore, the placement and separation rules for communication and power cables are based on the NESC safety rules, which generally assume metallic communication cables. For the special case of entirely dielectric (i.e., no metallic components) fiber-optic communication cables, the NESC significantly relaxes such rules (IEEE 2007). Such communication cables may be buried close (albeit not sharing the same duct) to power supply cables under relatively liberal conditions, e.g., subject to the maximum power supply voltages described earlier.

5.2.2.4 Alternative Joint-Use Trench Configuration. Figure 5-7 illustrates an alternative trench configuration that may be more conveniently deployed in some applications than the relatively deep trenches of Figs. 5-4 to 5-6. In this variation on Fig. 5-5, the vacant BCN ducts, limited to future communication cables, are placed at the same depth as the initial power conduits of Fig. 5-5 but horizontally separated by a 12-in. minimum. This configuration results in a shallower but wider trench.

There are a variety of possible embodiments of the current BCN concept, and the alternatives described herein do not exhaust the possibilities.

5.3 DUCT INSTALLATION

The most convenient time to install the BCN is during the original open-cut trench construction for the buried cable utilities, when additional

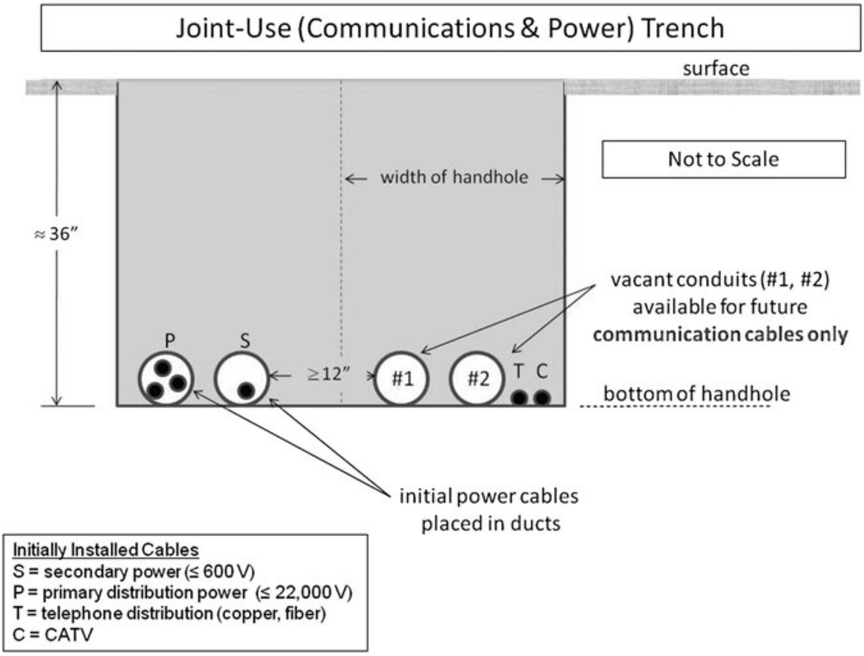

Figure 5-7. Joint-Use Trench, Including the Example BCN for Communication Only: a Shallower, Wider Trench Alternative (Trench Backfill Details Not Shown; see Section 3.2.2.1).

ducts and handholes may be readily placed as an overlay to the initially direct-buried cables, as illustrated in Fig. 5-1. In this case, the construction procedures for the placement of the conduits should be consistent with industry guidelines, as outlined in Section 2.2.2.4, including that recommended in ASTM F1668 (ASTM 2008a). If practical, the ability to maintain a uniform alignment and grade along most of the route would facilitate the future addition of a handhole at an intermediate location, should the need arise, as described in Section 5.2.1. In addition, the ability to maintain the nominal positions may facilitate the usage of the BCN upgrade capability for both communication and power, as described in Section 5.2.2.3. The maintenance of a (minimum) 12-in. spacing between duct surfaces may help avoid the need for imposing the rules for random separation between these types of facilities, depending on the future implementation of the ducts and cable routing at handholes.

In some cases, it is necessary or advantageous to use boring or drilling techniques, such as those discussed in Section 3.2.2.3. This technique typically includes applications in which the path must pass beneath obstacles, e.g., roads, railroad tracks, creeks, or wetlands. The two ducts may then be installed as a bundle, and their spacing would not conform to that suggested or indicated in Figs. 5-3 to 5-6. Also, their relative positions within the trench and handholes may vary along the route. The initial utility cables, or preferably small ducts for their later containment, may be installed simultaneously alongside the two BCN conduits, using an installation configuration such as shown in Fig. 5-8, or another possible configuration. The plastic BCN conduits are sufficiently flexible to be properly positioned in the vicinity of the handhole, especially for HDPE pipe, which is often used for such drilling and pulling operations.

The drilling techniques enable the BCN system to be installed in an established area, avoiding surface damage and associated restoration expenses. This installation is accomplished most conveniently concurrent with the placement of a new cable or cables, which would presumably require such boring or drilling procedures because of the original lack of the BCN or equivalent. The placement of the BCN using HDD has been successfully demonstrated (see Chapter 6).

Although the flush-mounted BCN handholes provide an obvious indication of the presence of the belowground network, the use of electronic markers or equivalent is recommended for facilitating future location of the initially installed direct-buried cables, conduits, and overall path of the trench (Fig. 5-9). Such information helps to reduce the vulnerability to damage from unrelated future construction and excavation. Alterna-

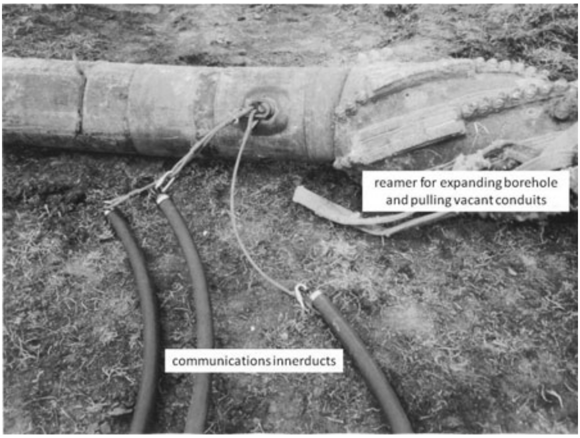

Figure 5-8. A Reamer for Simultaneously Installing Communication Innerducts with Conduits.

Figure 5-9. Commercially Available Markers and Locators (Courtesy of Telemark Solutions Inc.).

tively, a tracer wire may be installed externally, alongside, or internally, within one of the vacant ducts. For convenience, pull lines are available with a copper tracer wire incorporated within the line. Such items may be installed in one or both of the vacant BCN ducts after the installation of the network, or possibly included within the product pipe as supplied. Independent of any hardware or equipment used to facilitate the future location of the route, certified record ("as-built") drawings should be provided by the contractor, to be filed with the facility owner, clearly indicating the horizontal and vertical (depth) locations of the conduits, as well as any direct-buried cables, including their identity, in the completed installation. The information should be as accurate as possible, and within 6 in. of the true horizontal and vertical (depth) locations, as measured to the center of the ducts or direct-buried cables.

5.4 BCN HARDWARE REQUIREMENTS

5.4.1 BCN Ducts

Although the example BCN as described in Section 5.2 would function with various types of conduit, it is assumed that the most commonly used pipe materials would be used, i.e., polyvinyl chloride or high-density polyethylene (see Section 2.2.2.3). At present, conventional PVC pipe is the most commonly used such product for open-cut distribution trench installations, although HDPE would typically be used if the installation required a pulling operation, such as when boring or drilling. However, recent developments and innovations for pipes of both types of materials facilitate their deployment in either application.

A distribution duct size of 4 in. is typically deployed for the BCN, but larger pipe sizes, including 5-in. or 6-in. nominal diameter, are also feasible, at a correspondingly greater material cost, plus the need for associated handhole modifications. Table 5-1 provides the actual outer diameters (within appropriate plus-or-minus tolerance) of various size ducts, based on the iron pipe size (IPS) system, as well as recommended mousehole dimensions. Unless otherwise specified, 4-in. ducts are assumed.

For PVC applications, Schedule 40 pipe is recommended (NEMA 2003a). For HDPE applications, dimension ratio (DR) 11 or 13.5 is recommended[4] (ASTM 2008b). Table 5-2 provides dimensions corresponding to these pipes for the nominal 4-in. size. The inner diameters are important

Table 5-1. Common Distribution Duct Sizes (for IPS) and Corresponding Mousehole Dimensions

Nominal Pipe Size (in.)	Outer Diameter (in.)	Mousehole Width (in.)	Mousehole Height (in.)
3	3.500	4.25–4.50	4.75–5.00
4	4.500	5.25–5.50	5.75–6.00
5	5.563	6.50–6.75	7.00–7.25
6	6.625	7.625–7.875	8.125–8.375

Table 5-2. Dimensions for 4-in. Pipe

Type Pipe, Wall Thickness	Outer Diameter (in.)	Inner Diameter (Average) (in.)
PVC, Schedule 40	4.500	4.026
HDPE, DR 11	4.500	3.633
HDPE, DR 13.5	4.500	3.794

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[4] For distribution conduits installed by HDD, DR 11 is recommended.

with respect to determining the ability to adequately contain cables or subducts, as well as for selecting appropriate size duct plugs (see Fig. 2-14). In addition to PVC or conventional HDPE conduit, other innovative types of pipe may be appropriate; e.g., see Figs. 2-6 and 2-8.

For BCN configurations intended for communication upgrades only, orange color-coded duct may be used for both conduits; see Section 2.2.2.3. For BCN configurations in which the upgrade features may be used by power and communication cables, a neutral color (e.g., gray) should be implemented.

For BCN applications including individual service ducts (e.g., for electric power, telephone, or CATV) from adjacent terminals or equipment to local structures (homes or small businesses), as illustrated in Fig. 5-1, appropriately color-coded innerduct may be deployed. HDPE innerduct, of 1- to 2-in. diameter, and DR 11 or 13.5 wall thickness, may be installed for telephone or CATV lines. Larger diameter (e.g., 2- to 3-in.) pipe, including PVC, may be used for power lines.

5.4.2 BCN Handholes

Figure 5-2 illustrates a typical (generic) handhole geometry, such as that intended for use as part of the example BCN system described in Section 5.2. Although it is shown as a rectangular box, the units may be tapered or may contain various features consistent with providing the required strength and functionality. In general, the details of the design can vary, depending on the material and manufacturer. The overall dimensions, however, should be approximately as indicated, i.e., nominally 2 ft wide and 3 ft long, with a minimum depth of 36 in. Increased width, length, or depth may be desired or necessary, based on the requirements for the particular application, as specified by the relevant road authority (e.g., state or local) or utilities or as required because of manufacturing issues and product availability. In some cases, increased depth may be achieved by adding extensions onto basic modules, consistent with the manufacturer's intent. For the example BCN, the handhole is bottomless and contains two mouseholes at each end, aligned with those at the opposite end. For applications anticipating possible use of the BCN upgrade capability by both communication and power cables (see Section 5.2.2.3), it is preferable, although not essential, that the spacing between the mouseholes be compatible with a 12-in. minimum separation between the ducts, as indicated.

The illustrated handhole is intended to accommodate a nominal 4-in. duct. The mousehole openings are approximately 1 in. greater than the outer diameter of the pipe, allowing for easy capture during installation. In general, the dimensions of the mousehole openings shall be as indicated in Table 5-1 for various size ducts. Several ports (knockouts), or their equivalent, should be available on each longitudinal side of the handhole, of approximate dimensions (length and height) and locations as indicated in Fig. 5-2. The distance from the bottom of the handhole to the top of the upper row of ports is 12 in., and the distance from the bottom of the handhole to the top of the lower row of ports is 6 in. Individual ports shall be initially plugged or blocked to reduce the likelihood or degree of dirt intrusion. This blockage may be accomplished with a removable plug or by retaining sufficient material in or around the knockout portion until the time when access is required and the material is removed.

Handholes may be constructed of a variety of materials, including high-density polyethylene, fiber-reinforced polymer, polymer concrete, certified precast concrete, cast iron, or a combination of such materials, including steel reinforcing components or lids. The load capability of the handhole depends on the component materials and design details. The example BCN handhole would generally not be installed in an area deliberately exposed to vehicular traffic, therefore avoiding the need for the most heavy-duty units. Nonetheless, the handhole must comply with the strength specified by the relevant road authority (state or local) or utilities. There are a variety of industry documents and standards that specify load ratings for various applications, as described in Table 5-3. To satisfy a relatively wide range of applications, it is recommended that handholes designed and intended for the BCN application meet or exceed the “20K” vertical test load capability (or 20,800 lb[5]), and preferably satisfy the ANSI/SCTE 77 TIER 15 criteria, including 22,500-lb peak vertical load plus corresponding lateral loads (SCTE 2007). The TIER 15 level is sufficient to meet the requirements of many state departments of transportation for placement within the right of way, typically at the outer edge and away from the traveled way.

In addition to the strength requirement, there are various material and environmental test criteria. As a minimum, the handholes shall comply with the environmental requirements of SCTE 2007, including the following:

- accelerated service exposure,
- chemical resistance,
- sunlight (UV) resistance,
- water absorption, and
- flammability.

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[5] A peak vertical load of 20,800 lb corresponds to an AASHTO A-16 live load (16,000 lb) plus 30% impact, without an additional safety factor (ASTM 2007).

Table 5-3. Load Ratings for Handholes

Designation (Nominal Rating)	Application	Peak Test Load (Vertical)	Peak Test Load (Lateral)	Source
Telcordia—greenway	Minimal pedestrian, no vehicular traffic	1,700 lb	420 lb (18-in. unit)	Telcordia 2005*
Light-duty	Pedestrian—walkway	3,000 lb	NA	SCTE 2007
A-0.3 (300 lb/ft^2)	Pedestrian—walkway	390 lb/ft^2	≥30 lb/ft^2	ASTM 2005b
TIER 5	Sidewalk, occasional nondeliberate traffic	7,500 lb	900 lb/ft^2	SCTE 2007
Telcordia—pedestrian, light	Pedestrian and light incidental traffic	7,800 lb	2,600 lb (36-in. unit)	Telcordia 2005*
WUC Guide 3.6	Incidental traffic	10,400 lb	600 lb/ft^2	WUC 1988
A-8 (8,000 lb)	Light traffic	10,400 lb	>40 lb/ft^2	ASTM 2007
TIER 8	Sidewalk, nondeliberate traffic	12,000 lb	900 lb/ft^2	SCTE 2007
Telcordia—side road	Noncontinuous vehicular traffic	15,600 lb	5,200 lb (36-in. unit)	Telcordia 2005*
A-12 (12,000 lb)	Medium traffic	15,600 lb	>60 lb/ft^2	ASTM 2007
"20K"	Incidental, Light Traffic	20,000 lb	≥30 lb/ft^2 (ASTM C857)	Various suppliers
A-16 (16,000 lb)	Heavy traffic	20,800 lb	>80 lb/ft^2	ASTM 2007

Table 5-3. *Continued*

TIER 15	Driveway, parking lot, off-roadway, occasional nondeliberate heavy traffic	22,500 lb	1,200 lb/ft^2	SCTE 2007
H10** (8,000 lb)	Light traffic	22,568 lb	>40 lb/ft^2 (ASTM C857)	ASTM 2005b, 2007, 2009
TIER 22	Driveway, parking lot, off-roadway, occasional nondeliberate heavy traffic	33,750 lb	1,200 lb/ft^2	SCTE 2007
H15** (12,000 lb)	Heavy traffic	33,852 lb	>60 lb/ft^2 (ASTM C857)	ASTM 2005b, 2007, ASTM 2009
H20** (16,000 lb)	Heavy traffic—roadway	45,136 lb	>80 lb/ft^2 (ASTM C857)	ASTM 2005b, 2007, 2009

* "Objective" is increased by a factor of approximately 1.33.

** Precast concrete hanhole.

Source: Courtesy of Outside Plant Consulting Services, Inc.

5.5 BCN MANAGEMENT AND OPERATIONS

5.5.1 Joint-Use Agreements

An important issue in the deployment of the BCN relates to the practical joint-use aspects, such as the cooperative initial construction, operation, and maintenance of the facilities. In particular, responsibilities must be allocated for the following items:

- initial construction and installation of the BCN, including cost-sharing;
- control of future access to the handhole to allow entry in the event that a new cable must be added (see Section 5.5.2);
- assignment of conduits, when required, including specifying use of subducts, as appropriate;
- repair and maintenance of the conduits and handholes in case of damage or degradation; and
- maintenance of up-to-date records regarding the actual occupancy of the conduits.

The allocation of these and other responsibilities should be addressed in an appropriate joint-use agreement among the parties sharing the network. If one utility, organization, or government authority is sponsoring or constructing the original trench, allowing other utilities or parties to place their initial cables directly in the trench, to be overlaid with the BCN conduits and handholes, that sponsoring utility or organization may choose to assume most of the management responsibilities for the BCN. In the event of no single clear sponsor or owner of the trench and BCN facilities, it is recommended that the power company, if it is one of the parties sharing the BCN, assume most of the management responsibilities.

The parties owning or sharing the facilities would have to agree to appropriate and equitable compensation, including possible sharing of initial construction costs, determination of ongoing lease or maintenance fees, and adjustment to such fees based on future usage and occupancy of the available conduits. In some cases, a new user, not one of the original parties sharing the facilities, may desire access to an available conduit and would therefore be required to compensate the sponsor, owner, or original parties.

The joint-use agreement would also include various other responsibilities and obligations, including adherence to safety standards for belowground utilities, such as those required by the National Electrical Safety Code (IEEE 2007), including those indicated in Section 5.2.2.3.

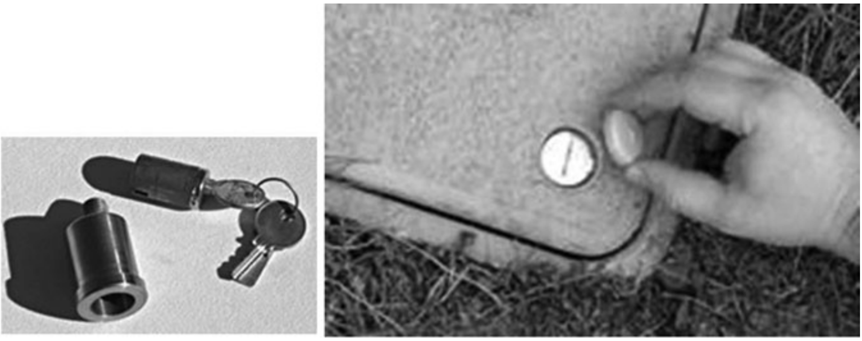

Figure 5-10. Commercially Available Lock for Handholes (Courtesy of Lock-Down Incorporated).

In general, it would be desirable that the deployment and use of belowground cable networks, or equivalent facilities, be encouraged in various construction permits issued by government that include the placement of buried utility cables. The permits may help clarify the respective roles of the parties using the facilities.

5.5.2 BCN Operations

Although a basic rule for joint usage of the handhole for the current BCN alternative is that no equipment or maintenance facilities should be placed within the cavity, it may be considered feasible to place an extra length (slack) of fiber cable within the handhole, as an alternative to burying the coil, after installation of the cable within one of the available conduits. This practice would be consistent with considering the handhole to be an extension of the trench, and not to be accessed routinely. Another exception would correspond to the extreme case of a single owner or user of the trench and BCN, as described in Section 5.2.2.1. In such instances, the handhole may be used to contain equipment or splices for the single user.

The use of subducts for allowing several cables to occupy a single, larger diameter conduit is discussed in Section 2.2.2.1. Therefore, on initial placement of a cable within a vacant conduit, the party should be obligated to simultaneously place such subducts into the assigned conduit, for possible future use by that party or others. Such a practice would typically be appropriate for small-diameter communication cables. To maintain the integrity of the conduit and subduct paths, the initial and subsequent users should also be obligated to utilize duct plugs to prevent water and debris from entering the duct paths. For example, Fig. 2-14 illustrates various types of plugs, including those appropriate for sealing vacant or occupied conduits. In general, the hardware and equipment discussed in Section 2.3.1 is applicable to the BCN conduits.

If considered necessary, increased security for the handhole may be achieved by use of security locks inserted into the lid (Fig. 5-10). The keys for entry should be retained by a responsible organization controlling the BCN, such as a government authority or designated utility (e.g., power company) (see Section 5.5.1). Such security is especially recommended for applications in which power cables may use the upgrade capabilities of the BCN (see Section 5.2.2.3).

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6

STATUS OF BELOWGROUND CABLE NETWORKS

The incorporation of a belowground cable network (BCN), such as that described in Chapter 5, into the design standards or procedures of road authorities can only occur over an extended period of time. The current manual of practice represents an important item in the support of such a trend. Another essential element in the ability to encourage the implementation of a BCN, or its equivalent, is the successful demonstration of its practical application in a variety of construction projects. In this regard, two related field trials have been successfully accomplished in a campus or residential environment, as described in detail in this chapter. Additional field trials, including along road facilities under jurisdiction of a state department of transportation have been planned or scheduled.

6.1 DESCRIPTION

During October and November 2008, two field trials of the example BCN were conducted along local roads in Arlington, Texas, within property controlled by the University of Texas at Arlington (UTA). The BCN networks were installed within the grassy strips adjacent to sidewalks on Mitchell Street and on South Davis Drive, intersecting streets within the campus. The objective was to provide UTA with a convenient network for the future installation of communication cables to serve local university facilities. The physical characteristics of the two areas are generally similar with respect to the surface obstacles associated with an established area. These obstacles include walkways, driveways, and landscaping. An additional major obstacle was present on South Davis Drive: a large culvert, approximately 6 ft below the surface, adjacent to a wide driveway entrance for a parking area. Because of the anticipated surface damage and potentially large restoration expenses, it was decided that trenchless methods should be considered for installing the BCN along both streets. One trial therefore included the use of HDD for placing the BCN conduits along a 600-ft route on Mitchell Street at a uniform depth of approximately 40 in., and the other trial used HDD to place the BCN conduits along a 1,600-ft route on South Davis Drive at a somewhat greater depth, especially in the vicinity of the culvert and driveway crossings. Before the start of construction, the existing utilities in the vicinity of the planned installation path, including telephone, electric power, gas, and water, were identified, located, and marked following proper procedures, including contacting the local "One-Call" system.

Neither of the UTA trials included the initial placement of any direct-buried cables. These installations would therefore not reflect some of the joint-use and cooperative issues (see Section 5.5) that tend to arise in cases more closely reflecting the nominal BCN recommended applications. Nonetheless, these applications demonstrate the feasibility of using trenchless technology to install a BCN in an established area while avoiding surface damage and associated restoration expenses. In many cases, this result would most conveniently be accomplished concurrent with placement of new cables, which would otherwise presumably require such boring or drilling procedures because of the original lack of the BCN or its equivalent. The required utility cables, or preferably small ducts for their later containment, may be installed simultaneously alongside the two BCN conduits, or possibly subsequently placed within one of the latter BCN ducts (see Section 5.3).

To be cost-effective, it was decided that the use of a relatively small mini-HDD machine and crew would be used, with the objective of simultaneously pulling back two 4-in. ducts along each trial route. The use of HDD in general, and mini-HDD in particular, therefore represented several challenges and opportunities:

- simultaneous pullback of two 4-in. ducts requiring a minimum (preferably larger) borehole diameter of 12 in.;
- available equipment with a maximum 20,000-lb pull load capability and a reamer of less than 12-in. diameter;
- anticipated tensile load on individual duct, during dual installation in limited borehole diameter, possibly exceeding safe pull strength of plastic pipe products typically used for such operations; and
- the need to place ducts at appropriate vertical and horizontal positions at handholes, consistent with the location and spacing of mouseholes.

Several preconstruction meetings were held, including the project coordinators, the customer (UTA), the contractor, and the pipe supplier, to increase the possibility of successfully meeting the project objectives. The construction procedures adopted were based on the results of these discussions.

6.2 FIELD-FUSED PVC PIPE

Because of the potentially high pipe tensile loads associated with the dual pullback into the minimal diameter borehole, aggravated by possible unequal distribution of such loads between the individual pipes, field-fused PVC pipe, of Schedule 40 wall thickness (see Section 5.4.1), was selected as the appropriate product pipe. This field-fused product is characterized by pull loads essentially equal to that of the individual PVC pipe segments, i.e., in excess of the almost 20,000-lb estimated installation forces (Slavin 2007) for a 1,600-ft pullback operation, assuming a single pipe installation. Thus, in theory, assuming that the mini-HDD equipment were capable of creating a stable, optimum-sized borehole for the entire 1,600-ft route along South Davis Drive, the pipes could be placed in one long pullback operation. In practice, however, the corresponding pull loads for a dual installation would be twice the capability of the cost-effective operation and equipment considered, not including the required force for expanding (reaming) the borehole. Thus, the ducts were installed in typically shorter segments, of several hundred feet each. The additional margin provided by the Schedule 40 PVC pipe was helpful in completing at least one problematic segment in which the pull forces unexpectedly exceeded anticipated loads (see Section 6.5).

Figure 6-1 shows the fusing operation as performed in the field, with completed pipe sections laid out as shown in Fig. 6-2. Figure 6-3 shows a typical fused joint.

6.3 HDD OPERATION

To maximize the capability of the mini-HDD machine, the contractor decided that, before pulling back the pipe, the borehole would be thoroughly reamed and cleaned, thereby minimizing the pullback loads imposed on the equipment. After the creation of a clean, stable borehole section, the full equipment capability might then be used to pull back the conduits. Soil tests performed before the operation indicated that the drilling operation would be through highly compacted clay. Such conditions are favorable with respect to maintaining the stability of the

Figure 6-1. Field Assembly Operation for Field-Fused PVC Pipe.

Figure 6-2. Completed Length of Field-Fused PVC Pipe.

created borehole, but they increase the time and effort required to perform the reaming operation, especially for the required final hole size. To help ensure success, the drilling fluid supplier provided on-site technical support in the selection of proper fluids and their usage. In this case, because of the high clay content, a polymer additive was considered appropriate.

Thus, after a pilot hole boring operation for each several hundred feet segment (Fig. 6-4), such as those spanning anticipated handhole locations, the reamer was attached to the drill string (Fig. 6-5), and the hole was

Figure 6-3. Field-Fused PVC Joint.

Figure 6-4. Initial Pilot Hole Boring with Mini-HDD Machine.

expanded and cleaned in increments of 50 ft. After each 50-ft pullback, the reamer was pushed forward to the far end, or to a local cleanout pit, to expel the cuttings (Fig. 6-6), which were then removed for proper disposal.

After establishment of the cleaned borehole along each several-hundred-foot bore path segment, the pair of assembled conduits were attached to the end of the drill string and pulled into that segment (Fig. 6-7). The machine was then moved to the next planned handhole location along the route, from which another segment was drilled to meet the previous path,

Figure 6-5. Reamer Connected to Drill String.

Figure 6-6. Purging Expanded Borehole of Cuttings.

with the reaming, cleaning, and pipe pullback operations repeated (Fig. 6-8).

For the purpose of providing technical data to aid in the interpretation of the project results, a monitoring system (Finnsson 2004) was used for directly measuring the drilling fluid pressure and tension applied to the pair of conduits during the pullback operation (Fig. 6-9). The supplier of the product provided on-site technical support during the installation.

Figure 6-7. Pullback of Two BCN Conduits.

Figure 6-8. Overlapping Conduits from Adjacent Pullbacks.

Figure 6-9. Tension and Pressure Monitoring System for HDD Operation.

6.4 MITCHELL STREET

The architecture for the Mitchell Street trial, including geometry and approximate handhole locations, is shown in Fig. 6-10. For the current applications, the location of the handholes is not restricted by the need to serve adjacent equipment terminals, allowing the units to be placed as convenient. In addition to the handhole installed at one end of the 600-ft route, a second handhole was placed at an intermediate position, as indicated.

For Mitchell Street, relatively lightweight HDPE plastic handholes with reinforcing steel bands and heavy-duty polymer concrete covers (of nominal 20K rating; see Section 5.4) were deployed. The handholes are of nominal 2-ft width and 3-ft length, although the precise dimensions vary from top to bottom because of the tapered geometry. The depth of these units is 42 in.; see Fig. 6-11.

The handholes were placed over the ends of the previously installed conduits. Because the conduits were pulled back together as a group, it was necessary to use the flexibility of the plastic pipes to align them with the vertical and horizontal positions at the mouseholes. This alignment was accomplished by extending the pit for the handhole 10–15 ft along the path on each side of the units (see Fig. 6-8), allowing sufficient room to maneuver the pipes. In one case, however, because of obstacles in the

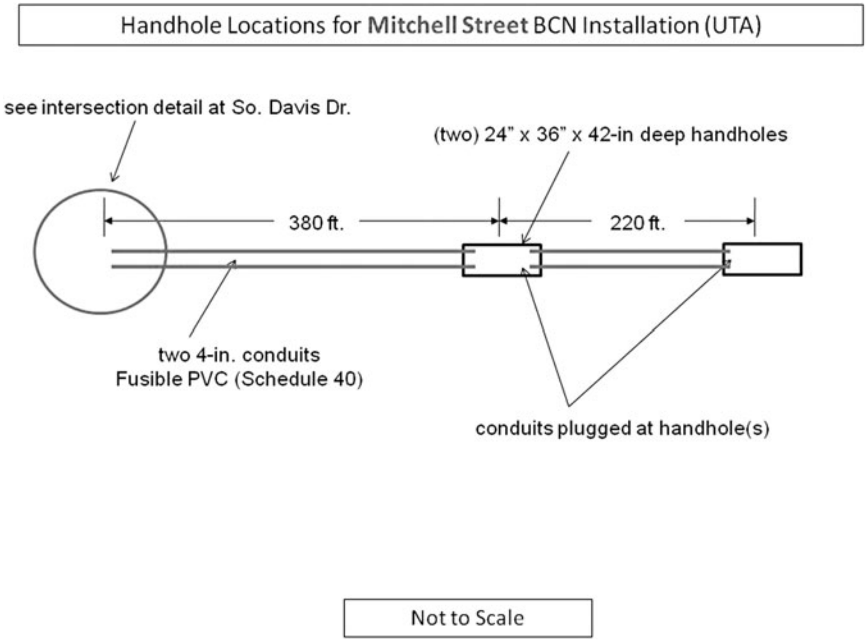

Figure 6-10. BCN Configuration Along Mitchell Street.

Figure 6-11. Lightweight Plastic Handholes for Mitchell Street.

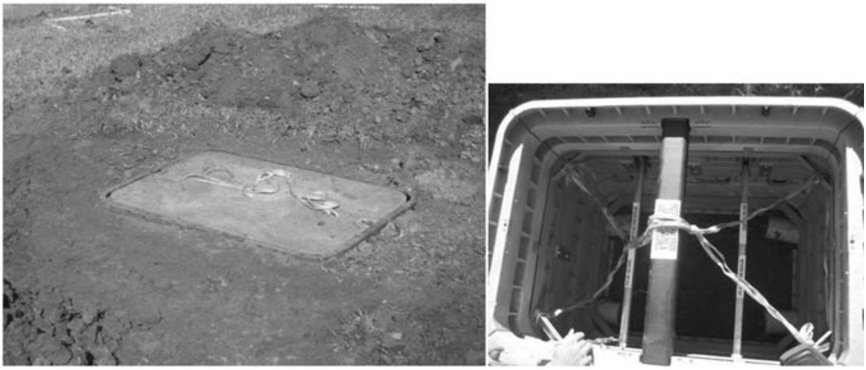

Figure 6-12. Installed Handhole (With and Without Cover), Mitchell Street.

vicinity of the handhole, combined with the lower flexibility of PVC pipe (e.g., relative to HDPE pipe) and the relatively wide separation of the mouseholes (12 in., consistent with Fig. 5-2), it was necessary to widen the mouseholes to accommodate the pipe positions. Because the handholes were placed at the ends of the separately installed pipe segments, the express option, in which the duct passes continuously through the handholes (Section 5.2.1) was not implemented for these trials.

An installed handhole is shown in Fig. 6-12.

6.5 SOUTH DAVIS DRIVE

The architecture for the South Davis Drive trial, including geometry and approximate handhole locations, is shown in Fig. 6-13. The pressure and tension monitoring system (see Section 6.3) was used for several of the path segments. In one problematic segment, the results indicated that excess drilling fluid pressure and increased tensile load occurred simultaneously and were possibly associated with a borehole collapse. In particular, a peak tensile load of almost 20,000 lb was detected, corresponding to an average of almost 10,000 lb per conduit, optimistically assuming equal load distribution. Such a tensile load is within the capability of the Schedule 40 fused PVC pipe, helping to ensure successful installation.

For South Davis Drive, although not required for this application, four relatively heavy-duty polymer concrete units with a TIER 15 rating (see Section 5.4.2) were installed; see Fig. 6-14. These handholes are also of nominal 2-ft width and 3-ft length, but with a depth of 36 in. In addition

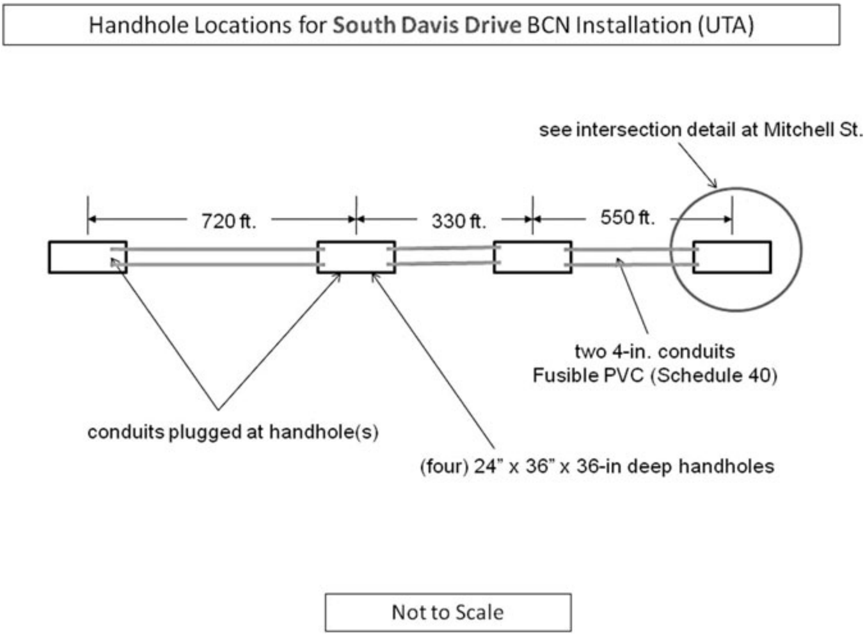

Figure 6-13. BCN Configuration Along South Davis Drive.

Figure 6-14. A TIER 15 Polymer Concrete Handhole for South Davis Drive.

to the handholes installed at the ends of the 1,600-ft path, handholes were placed at two intermediate locations, as indicated.

Similar to the Mitchell Street trial, the handholes were placed over the ends of the previously installed conduits. Because of the closer spacing of

Figure 6-15. Installed Handhole (With and Without Cover), South Davis Drive.

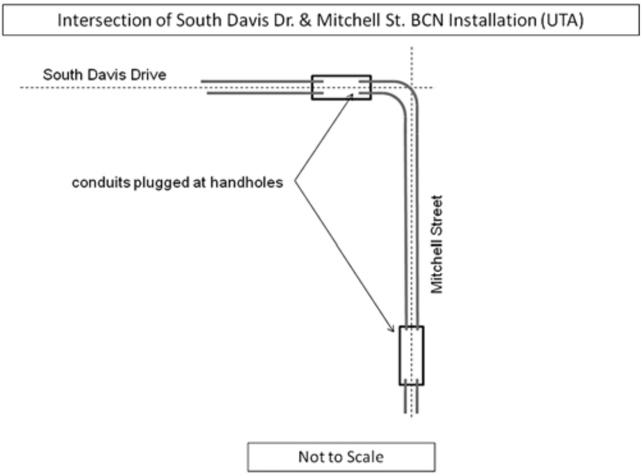

Figure 6-16. BCN Configuration at Intersection of the Two Trial Routes.

the mouseholes for these units, there was no difficulty in aligning the conduits at the entry and exit. An installed handhole is shown in Fig. 6-15.

6.6 INTERSECTION OF MITCHELL STREET AND SOUTH DAVIS DRIVE

Although the two trial routes are on different streets, they were able to be interconnected at their intersection, as illustrated in Fig. 6-16.

The connection at the corner allows the possibility of a cable being installed in a single operation along the cumulative distance of both routes, without the need for a splice at the intersection. The ability of successfully achieving such an installation length depends on the type of cable and the placement method. In particular, lightweight fiber-optic cables may be readily placed such distances using blown-cable placement techniques (see Section 4.3). For other cases in which such a placement length is not possible, the access to the ducts at intermediate locations (handholes) will facilitate the required installation.

6.7 COMPLETION

As a final step in the construction, a tracer wire was installed along the BCN route within one of the conduits. In this case, a pull tape with an incorporated copper tracer wire was installed within one of the conduit paths (see Section 5.3). This installation was accomplished by using an air compressor to blow the tape along each segment spanning sequential handholes. The temporarily removed conduit plugs were then replaced to maintain the integrity of the duct paths.

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GLOSSARY

aerial lines: Outdoor utility lines, including electric power and communications, installed on pole lines; also referred to as "overhead lines."

asset management: The management of the physical assets of a company or organization to maximize their efficient, long-term usage.

American Telephone & Telegraph (AT&T): A major communication company, formerly including the Bell Telephone System operating companies, Western Electric manufacturing facilities, and Bell Laboratories research, development, and design organization.

as-built: Information provided by the contractor, typically in the form of drawings, indicating the final location, including horizontal and vertical (depth), of recently installed underground facilities; also referred to as "certified record drawings."

Bell System Practices: The technical documents used by the original Bell Telephone System employees who performed repair and maintenance of the telephone system, including central office equipment, telephones, wiring of homes, and cable installation.

belowground plant: A direct-buried facility or underground conduit system.

bend radius: The degree to which a cable, duct, rod, or other longitudinal object may be bent into a circular shape; typically quantified by the corresponding "radius of curvature," but in directional drilling terminology, sometimes quantified by the circumferential distance around a quadrant of the smallest circular arc in which a drill rod may be safely bent.

bonding: Electrical connecting of metallic parts, intended to maintain common electrical potential, such as between cable shields or neutrals.

boring: A general term describing the procedure for creation of a hole beneath the ground, typically by use of a piercing tool (also called a pneumatic mole), rod pusher, or directional drilling machine.

belowground cable network (BCN): A construction method for utility cables combining the advantageous features of direct-buried construction and underground conduit systems, e.g., an integrated system of a minimal number of vacant ducts, to be available to electric power, communication utilities, or both sharing a single trench, as necessary, to meet future needs, with the ducts accessed at strategically located handholes; see "hybrid."

cable grip: Hardware grasping or holding the end of a cable, allowing a person or machine to pull the cable into a pipe.

cable jacket: The outer covering of a cable, intended to provide mechanical or environmental protection.

cable-in-duct: Cable preinstalled within a flexible duct, typically high-density polyethylene, allowing the cable and protective pipe to be installed in a single operation and avoiding the need for a secondary operation for installing the cable into the duct path.

capstan effect: The escalating increase in tensile force required to pull a cable or rope around a curved surface because of the increased friction associated with the normal pressure caused by the initial tensile force itself.

CATV: Originally used to as an acronym for a cable television system, a broadband communication system capable of delivering multiple channels of programming, generally by coaxial cable, but also integrating fiber-optic and microwave links; many CATV service providers also offer telephone and internet services to their subscribers.

certified record drawings: Information provided by the contractor, typically in the form of drawings, indicating the final location, including horizontal and vertical (depth), of recently installed underground facilities; also referred to as "as-built" drawings.

chute-plowing: A category of cable plowing that uses a plow blade with an internal slot that creates a slit in the ground and simultaneously allows a cable to be passed through the slot to the bottom of the created slit.

coaxial cable: Cable constructed of an inner metallic conductor surrounded by a concentric outer conductor, maintained at ground potential, capable of transmitting electrical signals for communication at extremely high frequencies or data rates.

coefficient of friction: See "Coulomb friction."

conduit: See "pipe."

controlled environment vault (CEV): A belowground vault designed to be waterproof and environmentally controlled, capable of housing sensitive electronic equipment.

Coulomb friction: The theoretical model that assumes that frictional drag is proportional to the local normal pressure, with the proportionality constant designated as the "coefficient of friction."

copper cable: Cable made of individual copper wires, typically arranged in pairs, capable of conducting electrical signals for communication.

dimension ratio (DR): The outer diameter of pipe divided by the wall thickness.

direct-buried plant: Outdoor equipment, hardware, or cables placed within the ground in intimate contact with the soil.

direct-buried cable: Communication or power cable designed to be placed belowground without additional covering or protection.

directional drilling: See "horizontal directional drilling."

distribution: Outside plant facilities to provide service to customers, including lines along local roads and streets, or other access corridors, as well as service lines or laterals.

duct: See "pipe."

duct rodder: A thin, flexible stick used for penetrating an empty (or partially occupied) duct or pipe to pull back a rope for subsequent installation of a cable; it may also be used for cleaning a duct.

feeder: An outside plant facility spanning a relatively long distance to provide large-capacity power or communication service to a local distribution area.

fiber cable: See "fiber-optic cable."

fiber-optic cable: Cable constructed of groups of individual optical fibers, typically made of glass, capable of transmitting optical signals for communication at extremely high data rates; also referred to as "fiber cable."

guided boring: See "mini-horizontal directional drilling."

handhole: Part of a belowground system that allows access to cables and possibly contains related hardware or splices but of insufficient size to allow personnel entry.

horizontal directional drilling (HDD): A method of trenchless technology using a surface-mounted drill rig with steering capability to bore a pilot hole and pull back product pipe or utility cable; also referred to as "directional drilling."

hybrid: A combination of two or more items or processes, such as a construction system combining the advantageous features of direct-buried construction and underground conduit systems; see, e.g., "belowground cable network."

innerduct: A relatively small diameter plastic pipe (e.g., 1 to 2 in.) or other material used to subdivide a larger conduit into several paths, allowing multiple small-diameter cables to be conveniently placed within the singe larger conduit; some types may also be used in direct-buried applications to provide a convenient, protected path for buried cables; see "subduct."

intelligent transportation system (ITS): A system incorporating information and communication technology to transport infrastructure and vehicles to improve safety and to reduce vehicle wear, transportation times, and fuel consumption.

joint use: Sharing of structures or facilities, including poles, underground conduit systems, or trenches by several utilities or organizations using cables, such as electric power and communication (telephone, CATV) companies.

life-cycle cost: The effective long-term cost of an item or process, including initial expenses as well as ongoing costs (e.g., maintenance expenses), typically calculated on a present-worth basis reflecting anticipated interest and inflation rates.

manhole: A part of an underground conduit system of sufficient size to allow personnel entry; the belowground structure provides access to the individual ducts, allows cables to be organized and spliced, and provides space for equipment and other hardware; manholes are typically not waterproof or environmentally controlled; also referred to as a "vault."

maxi-horizontal directional drilling (maxi-HDD): A category of HDD used for relatively long distances and large-diameter pipes, such as those associated with major river crossings.

microduct: A small-diameter (fraction of an inch) plastic tube designed for multiple placement within a larger duct for facilitating the efficient placement of small-diameter, lightweight fiber-optic cables.

midi-horizontal directional drilling (midi-HDD): An intermediate category of HDD between mini-HDD and maxi-HDD.

mini-horizontal directional drilling (mini-HDD): A category of HDD used for relatively short distances and small-diameter pipes, such as those associated with local distribution lines; also known as a "guided boring."

mole: See "piercing tool."

open-cut method: Belowground construction method in which the surface is disturbed, typically in a trenching operation.

outside plant: Outdoor facilities, including structures, equipment, hardware, and cables used by electric power and communication utilities to provide transmission and distribution functions.

overhead lines: See "aerial lines."

piercing tool: Equipment used to create a horizontal hole in the ground, using a properly aimed missile propelled by pneumatically powered internal impact loads; also known as a "pneumatic mole."

pilot hole: The initial path created during a boring operation, which is sometimes expanded to a larger diameter.

pipe: A hollow cylinder or tube for conveying or containing liquid, gas, or solid material, including cable; also referred to as a "conduit" or "duct."

plowing: A method of direct burial of a cable in which a plow blade penetrates the ground, simultaneously installing the cable into the created slit or cavity in the ground; see "chute-plowing" and "pull-plowing."

pneumatic mole: See "piercing tool."

power cable: Cable containing metallic conductors, typically copper, aluminum, or both for transmitting electric supply current at low or high voltages.

primary power: Relatively high voltage (e.g., 14,000 V) electric power provided along distribution lines, to be converted to low-voltage secondary power through local transformers for delivery to customers; see "secondary power."

pull-plowing: A category of cable plowing that uses a bullet at the end of the plow blade to create a cavity beneath the surface, while simultaneously pulling the cable into the cavity.

radius of curvature: The distance from the center of a circle, or a segment thereof, to the perimeter; also referred to as "radius"; see "bend radius."

random separation: Lack of deliberate (minimum of 12 in.) separation between cables placed within a common (joint-use) trench.

right of way: A longitudinal strip of land, in which the utility companies have access to place cables and facilities to perform their function as a utility.

secondary power: Electric supply power provided to customers at relatively low voltage, e.g., 120–240 V; see "primary power."

service lateral: The cable or wire connected to the portion of a distribution cable installed along the right of way or other access corridor.

subduct: Small plastic pipes or fabric cells used to divide a larger duct or conduit into several paths capable of accommodating relatively small diameter, typically fiber or coaxial, communication cables; see "innerduct."

sweep: A bend in a conduit system, which may be accomplished by insertion of a rigid elbow (e.g., PVC) or by bending flexible pipe (e.g., HDPE).

subsurface utility engineering (SUE): An engineering practice that manages risks based on the use of utility mapping at appropriate quality levels, utility coordination, utility relocation design, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies, and utility design.

trenchless technology: A construction method for renewing or replacing utility lines belowground without the use of open-cut methods or significant surface disturbance.

underground conduit system: A parallel network, or array, of pipes or ducts, used for housing and protecting cables placed within, spanning the distance between periodically spaced manholes or structures.

vault: See “manhole”; some vaults may be designed to be waterproof and environmentally controlled, capable of housing sensitive electronic equipment; see “controlled environment vault.”

wireless: Facilities and technologies capable of transmitting communication or other information without the need for physical cables; see “wireline.”

wireline: Physical cables for transporting electric power or communication signals, in contrast to wireless transmission facilities, such as those supporting cellular communication; see “wireless.”

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