National Cooperative Highway Research Program

NCHRP Synthesis 242

Trenchless Installation of Conduits Beneath Roadways

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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National Cooperative Highway Research Program

Synthesis of Highway Practice 242

Trenchless Installation of Conduits Beneath Roadways

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the 'American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to geologists; geotechnical, construction, and maintenance engineers; other state DOT personnel involved with the planning, design, and permit issuance for conduits beneath roadways; local transportation agencies; utility contractors and consultants; and trenchless construction equipment manufacturers. It describes the current state of the practice for the use of trenchless technology for installing conduits beneath roadways. Trenchless construction is a process of installing, rehabilitating, or replacing underground utility systems without open-cut excavation. The synthesis is focused on trenchless technology for new installations.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board describes the trenchless installation technologies (methods, materials, and equipment) currently employed by state DOTs and other agencies to install conduits beneath roadways. The synthesis presents data obtained from a review of the literature and a survey of transportation agencies. For each technology identified, information is provided to describe the range of applications, basis for technique selection, site specific design factors to be considered, relative costs, common environmental issues, and example specifications. In addition, information on emerging technologies and research needs is presented.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Tom Iseley, Ph.D., P.E., Executive Vice President, Iseley Enterprises, Inc., and Sanjiv B. Gokhale, Ph.D., P.E., Purdue University School of Engineering and Technology, Department of Construction Technology, were responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Arnold Aronowitz, Chief Geotechnical Engineer, Port Authority of New York and New Jersey (retired); David Bennett, Chief, Soils Research and Testing Center, Department of the Army, U.S. Waterways Experiment Station, Corps of Engineers; John Hodgkins, Deputy Chief Engineer/Director, Project Development, Maine Department of Transportation; Douglas J. Ivor-Smith, Senior Manager, Brown and Root, Inc.; G.P. Jayaprakash, Engineer of Soils, Geology, and Foundations, Transportation Research Board; Steven R. Kramer, Principal, Jason Consultants International, Inc.; Timothy J. Lewis, Highway Engineer, U.S. DOT/Federal Highway Administration; Priscilla P. Nelson, Program Director, Directorate for Engineering, National Science Foundation; Tom Nelson, Chief Construction Engineer, Washington State Department of Transportation; Jesus M. Rohena, Tunnel Engineer, U.S. DOT/Federal Highway Administration; and Raymond L. Sterling, CETF Professor of Civil Engineering, Director of Trenchless Technology Center, Louisiana Tech University.

This study was managed by Stephen F. Maher, P.E., Senior Program Officer, who worked with the consultants, the topic panel, and the 20-5 project committee in the development and review of the report. Assistance in topic panel selection and project scope development was provided by Sally D. Liff, Senior Program Officer. Linda S. Mason was responsible for editing and production, with assistance from Susan E. Brown. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

TRENCHLESS INSTALLATION OF CONDUITS BENEATH ROADWAYS

SUMMARY

More than 90 percent of the roadways in the United States were constructed before 1950. Since then, vehicle ownership and total travel mileage have increased, resulting in higher traffic density. Societal impact resulting from conventional open-cutting to install utility conduits beneath roadways has increased significantly because of this higher traffic density.

At the same time, public demand for access to various utilities has increased considerably. The need to replace much of the deteriorated underground utility infrastructure and to expand utility services will increase the need for conduits to intersect roadways. This intersection of roadways and underground conduits is critical and often requires special design, construction, and maintenance considerations. The need to minimize traffic disruption has increased the need for cost-effective alternatives that do not require roadway excavation.

Trenchless technology is a relatively new term that describes the installation of conduits beneath roadways without open-cutting. The term has been used on a global basis since the mid-1980s. However, some of the methods now referred to as trenchless methods are not new. For example, auger boring and slurry boring have been used since the 1940s, and pipe jacking has been used since the early 1900s. These methods are referred to as road boring techniques or horizontal earth boring techniques. Nevertheless, many new trenchless techniques have been introduced and many advancements have taken place with the more traditional techniques. Although most of these methods require excavation for shafts, shaft locations usually can be selected to avoid or minimize traffic disruption.

It is anticipated that the use of trenchless technology will continue to increase because of its inherent advantages of minimizing disruption to society and reducing environmental impact. Another driving force behind this increase is the benefit of avoiding or minimizing the handling, volume, treatment and/or disposal of contaminated soil. In many situations, these techniques have become cost-effective alternatives to traditional open-cutting methods.

State departments of transportation (DOTs) are being asked by utility owners and contractors to evaluate the feasibility and compatibility of trenchless methods for a wide range of utility installations. In some cases, the DOT is directly involved in the design and construction of a trenchless project, whereas, in other cases, the DOT is responsible for issuing a permit to a utility owner for the installation of conduits beneath its roadways. Unfortunately, the use of a trenchless technique that is incompatible with the parameters of a particular roadway crossing can result in failure. The most common type of failure resulting from trenchless construction of conduits beneath roadways is subsidence or heave of the pavement surface. An additional area of concern is damage to nearby facilities and utilities, which can be catastrophic.

This synthesis describes eight trenchless construction techniques: (1) auger boring, (2) slurry boring, (3) pipe jacking, (4) microtunneling, (5) horizontal directional drilling, (6) pipe ramming, (7) soil compaction methods, and (8) utility tunneling. The main features and range of applications, productivity issues and special concerns, current DOT practice, and emerging technologies of these methods are described. Each description includes a range of typical unit costs and typical capital equipment costs, the accuracy that can be

achieved, space requirements, compatible pipe materials, and compatible soil conditions. In addition, a case study is presented for each method that illustrates the principles and practices associated with the trenchless technique.

The most recent methods being used to install conduits under roadways, pipe ramming, microtunneling, and horizontal directional drilling, are not always addressed in DOT specifications. A survey of state DOTs indicated that states' experience with trenchless technology varies considerably. Interviews with state transportation officials indicated that trenchless technology experience of districts within a state also varies. The survey indicated that the DOTs are less familiar with the characteristics associated with these newer methods.

The survey pointed out that no DOT specification addresses all techniques. In fact, most DOT specifications only address one or two of them. The survey demonstrated a trend in the increased use of trenchless technology and that almost all respondents have no, or very little, training in the application of trenchless techniques. DOTs expressed concern for ground movement, accuracy, safety, and traffic disruption.

Installing conduits beneath roadways with trenchless technology requires not only different equipment but also different personnel skills than are needed for open-cutting. For example, the operator of trenchless equipment is attempting to install something without being able to see the excavation, spoil removal, and conduit installation process. Thus, not only is it critical to ensure that the proper equipment and method are selected for a particular application, but also that the operator and crew have adequate skills and experience.

This synthesis describes the trenchless technologies that are available to help DOTs install new utility conduits beneath their roadways; it does not address the trenchless techniques available to rehabilitate existing underground conduits. An overview of the development of the trenchless technology industry and sources of information are included. The synthesis provides a classification system that includes major factors that affect the selection and use of trenchless alternatives. There is no one method that is compatible for all types of conduits under all possible conditions. The DOT, utility owner, and contractor should be aware of the capabilities, limitations, and risks associated with each technique.

The trenchless technology industry is constantly changing. Technology for installing conduits that was not available a few years ago exists today. It is important that this technology continue to expand so that the industry can solve tomorrow's complex underground infrastructure problems with tomorrow's technology. However, successful projects require more than advanced technology. Success requires that DOTs, utility owners, consultants, contractors, and equipment and material manufacturers and suppliers work together. For example, DOTs can benefit from providing guidelines to utility owners and their consultants on trenchless technology options that are acceptable for installing utility conduits beneath various types of roadways. The development of these guidelines should involve input from utility owners, consultants, contractors, and equipment and material manufacturers and suppliers. Utility owners and consultants would be responsible for developing detailed design drawings and specifications in accordance with general guidelines, which would then be submitted to the DOT for approval. The DOT guidelines would facilitate communication between all parties to ensure that compatible methods and materials are being used for each installation.

CHAPTER ONE

INTRODUCTION

Utility firms provide necessary services to the public. These services include water, sewer, stormwater drainage, district steam and cooling, electricity, gas, telephone, and cable services. State departments of transportation (DOTs) are responsible for ensuring the safety, traffic-carrying ability, and physical integrity of their road facilities. Installing utility conduits beneath roadways can affect these factors; therefore, it is essential that DOTs regulate these activities (*1*). This requires cooperation and interaction between the DOTs and utility owners, and both need to understand the alternatives for installing conduits beneath roadways.

This chapter presents (1) a background of the development of the trenchless technology industry, (2) the objectives of the synthesis, (3) a description of the sources of information used to prepare the synthesis, and (4) the organization of the synthesis.

BACKGROUND OF THE INDUSTRY

Trenchless technology (TT) consists of a wide range of methods, materials, and equipment for installing new or rehabilitating existing underground utility systems. TT encompasses a wide range of nondestructive underground utility inspection and location techniques. The scope of this synthesis is the trenchless methods, materials, and equipment required to install new conduits under roadways.

The development, selection, and use of TT has expanded rapidly since 1985. The reason for this rapid growth is the desire to install or rehabilitate underground utility systems cost-effectively, with minimum impact on society and the environment. Figure 1 illustrates a pipeline being installed with a trenchless installation method.

Execution of a TT project differs substantially from that of traditional methods. To be successful, TT projects require more intensive site investigation and appropriate planning, design, and installation methods. Without these ingredients, field problems are likely. Field problems during construction often result in far greater impacts to society and the environment than occurs with traditional open-cutting methods. For example, a trenchless technique was selected for the installation of a concrete drainage pipe under the runway at T.F. Green Airport in Warwick, Rhode Island, in 1994. This method was selected because it permitted the installation of a large diameter pipe beneath the runway without interrupting air traffic to excavate the runway. However, construction related problems (i.e., operator error) caused large sink holes and voids. Consequently, the runway was closed and a strip 11 m (35 ft) wide was excavated across the entire runway to eliminate the voids (*2*). Proper site investigation, planning, design, and selection and use of compatible construction methods, materials, and equipment can prevent these types of problems.

Installing utility conduits under roadways without excavating a trench is not a new concept for many DOT design and construction engineers, permit reviewers, and administrators. Various boring, jacking, driving, and tunneling methods have been used successfully since the early 1900s. However,

FIGURE 1 Conduit being installed under a roadway with a trenchless installation method.

significant technical advancements and innovations have taken place in recent decades, resulting in new methods, materials, and equipment and enhancements to traditional trenchless methods. The rate of growth in the TT industry has been so rapid that it is difficult to keep abreast of innovations and developments *(3)*.

In the mid-1980s, many developments in the installation and rehabilitation of underground utility systems without digging trenches, often referred to as "no-dig" technology, occurred. However, there was no effective mechanism for providing interested parties with TT information. Therefore, a group of professionals in the United Kingdom conducted the first International "No-Dig" Conference, which was held in London in 1985. The overwhelming success of this event led to the development of the International Society for Trenchless Technology (ISTT) in 1986.

The objective of ISTT is to advance the science and practice of TT for the public benefit and to promote education, training, and research. The formation of ISTT is significant because it was the beginning of an industry structure to support the continued rapid expansion of the TT industry. As a result of the establishment of ISTT, the term trenchless technology became accepted worldwide.

During ISTT development, events in the United States resulted in the development of a structure to support the growth of the TT industry in North America. In 1987, the Indiana Department of Transportation (INDOT) funded a research project at Purdue University to develop construction specifications for highway projects requiring horizontal earth boring and pipe jacking techniques (*3*). The researchers invited the National Utility Contractors Association (NUCA) to provide input into specification development. At the time, NUCA was the only trade or professional organization with a standing committee on horizontal earth boring.

NUCA's Committee for Horizontal Earth Boring, now known as the Trenchless Technology Committee, became very involved in the INDOT project. In 1981 and 1986, through the committee's efforts, NUCA published two manuals that represented the most extensive guidelines for several of the more traditional trenchless techniques (*4,5*).

Beginning in the late 1970s and early 1980s, major research and development initiatives that led to the commercialization of guided boring were being sponsored by the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI). However, as a result of the awareness that developed at the INDOT project regarding the global TT industry, it was recognized that much technological development was taking place outside the United States and that the U.S. underground utility industry was severely fragmented. No comprehensive industry structure similar to the transportation industry existed. Various trade and professional organizations operated independently. As a result, little was being done to establish research programs that could generate the next level of TT. This concern resulted in the establishment of the Trenchless Technology Center (TTC) at Louisiana Tech University in 1989 and the development of the North American Society for Trenchless Technology (NASTT), an affiliate chapter of ISTT, in 1990.

OBJECTIVE OF THE SYNTHESIS

A critical area of application for trenchless construction is beneath highways, streets, railroads, and other transportation arteries. Conduit installation beneath transportation arteries needs to be implemented with minimal disruption to vehicular traffic and minimal effects on the long-term integrity of existing facilities. The technology has advanced more rapidly than the support needed to document performance of important design parameters. For example, there is still limited technical data, knowledge, and understanding of the relationships among soil characteristics, advancement and installation mechanisms, soil loads, and conduit material characteristics.

This synthesis describes TT methods, materials, and equipment currently employed by transportation and other agencies to install conduits beneath roadways. For each of these three items, text and tabular summaries are provided to describe the following:

- The range of applications;
- The basis for selection of techniques for specific applications;
- Site-specific design factors that need to be considered;
- Relative cost information, including direct and indirect costs;
- Common environmental issues;
- Current DOT practices, with examples of specifications; and
- Emerging technologies and research needs.

Many books, technical reports, professional journals, technical publications, and computer databases contain vast amounts of information on the TT techniques identified. Existing sources of important technical and cost information relevant to each of the techniques are identified throughout the synthesis.

The profile of current DOT practices was developed by means of a questionnaire and interviews. This profile addresses the following:

- Techniques with which DOTs are familiar,
- Techniques covered in DOT specifications,
- Major concerns with the use of TT,
- Cost of specific applications,
- Productivity associated with a specific application,
- Rate of change in the use of TT,
- The extent to which TT is being used, and
- The need for specialized training.

This synthesis is intended to be a reference document for DOT staff members who have varying responsibilities during the different phases (i.e., planning, design, construction, and permit issuance) of a project requiring trenchless installation of conduits beneath roadways. However, it is not intended to represent definitive guidelines. Staff responsible for project planning, design, and construction may wish to use the synthesis as a starting point to obtain a basic understanding of issues associated with certain techniques and to identify ources for more detailed information.

Sources Of Information

An extensive review of pertinent domestic and international literature and ongoing research relating to trenchless installation of conduits beneath roadways was conducted. A keyword search on TT was conducted using the Transportation Research Information Service (TRIS) computerized information database. This information was supplemented with trade and professional association publications, professional journals, research reports, and several books. These sources are identified in the reference list.

A comprehensive questionnaire was developed, and 146 were sent by mail to the following:

- DOTs in all 50 states, Washington, D.C., Puerto Rico, and 10 provinces in Canada;
- Federal Highway Administration (FHWA) representatives;
- Municipal departments of public works;
- Utilities;
- Contractors and consultants;
- Universities; and
- Related organizations.

Figure 2 illustrates the distribution of the questionnaire. Because of the nature of the topic and the substantial amount of information requested, the DOTs were asked to provide specific information on their experiences with TT during the past 3 years only. Seventy-one responses were received. Figure 3 illustrates the distribution of the responses according to industry segment. Information obtained from the questionnaire that relates to a specific technique is presented in the chapter that discusses that technique; general observations are presented in Chapter 2.

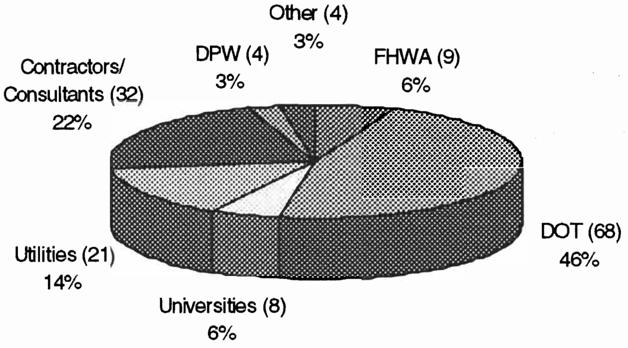


FIGURE 2 Distribution of questionnaire.

Organization of the Synthesis

Chapter 1 provides an overview of the TT industry and the objectives of the synthesis. Chapter 2 presents a classification system for techniques used to install new conduits beneath roadways. The chapter defines appropriate techniques, identifies the factors that affect technique selection, and provides a technique selection process. Chapters 3 through 8 focus on specific techniques. The information provided for each technique includes (1) a brief description of the technique, (2) a description of the main features and range of applications, (3) typical productivity ranges and factors that affect productivity and cost, (4) current DOT practices, (5) a description of emerging technologies, and (6) a case study that emphasizes significant characteristics of the technique. Chapters 9 and 10 are the summary and conclusions, respectively. Chapter 9 presents several tables on cost and other major operating parameters. A glossary of terms and acronyms appears at the end of this document.

A copy of the questionnaire is provided in Appendix A, and a summary of the replies received are in Appendix B. A listing of related organizations is found in Appendix C.

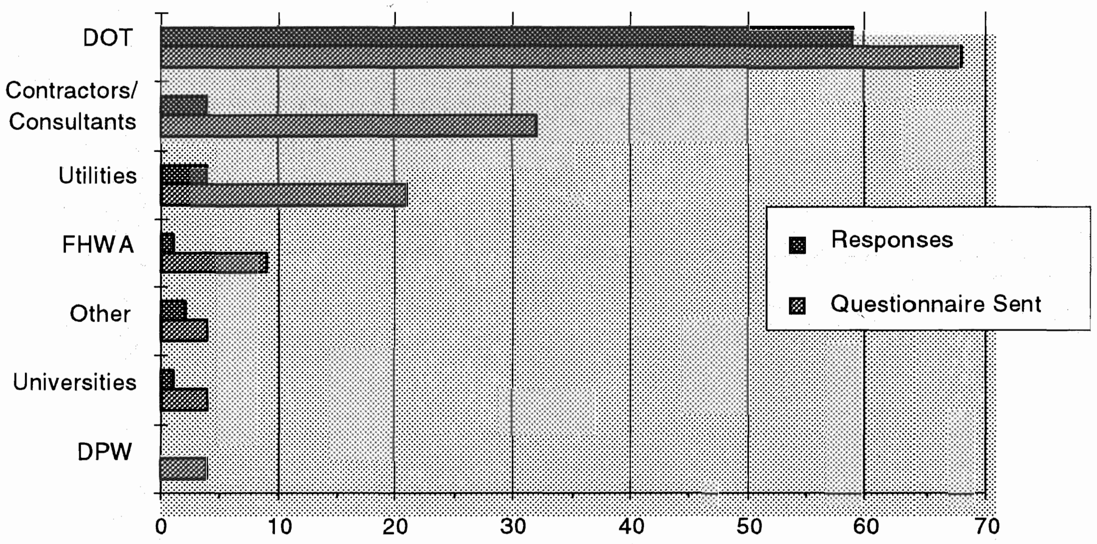


FIGURE 3 Distribution of questionnaire responses.

CHAPTER TWO

TRENCHLESS TECHNOLOGY ALTERNATIVES

The first part of this chapter presents an overview of the family of trenchless methods that are used to install conduits beneath roadways. Each method is defined and a set of major characteristics is provided to help distinguish differences among the methods. The latter part of the chapter focuses on how each method is selected for a particular application. Each application is site-specific and needs to be considered individually. What is appropriate for a rural roadway may not be appropriate for an interstate highway.

TRENCHLESS METHODS FOR INSTALLING CONDUITS BENEATH ROADWAYS

There exists a large family of trenchless methods for installing utility conduits beneath roadways. For this synthesis, a broad definition is applied to the term "utility." A utility is a privately, publicly, or cooperatively owned line, facility, or system for producing, transmitting, or distributing communications, cable television, power, electricity, light, heat, gas, oil, crude products, water, and steam to the public. A utility may process wastewater and disburse stormwater not connected with highway drainage and may include a fire or police signal system or street lighting system.

Thomson (*6*) estimates that roughly 241,350 km (150,000 mi) of new service lines and cables will be laid each year throughout North America. In addition, millions of house service connections will be needed, which Thomson's figures do not take into account. Figure 4 illustrates the individual shares of agencies responsible for underground installation work in North America. The range of conduit sizes varies from small communication cables to large-diameter sanitary and storm sewer mains (Figure 5). The types of conduits range from gravity flow sewer lines that must be installed at depths greater than 15 m (50 ft) on critical grade with a straight alignment, to pressure lines that require minimum ground cover, with large tolerances for line and grade.

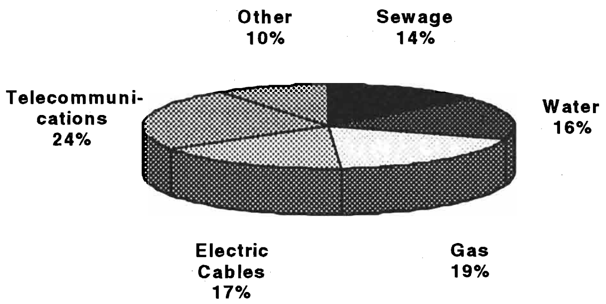


FIGURE 4 Breakdown of estimated pipeline replacement and new pipeline installation in North America by responsible agencies.

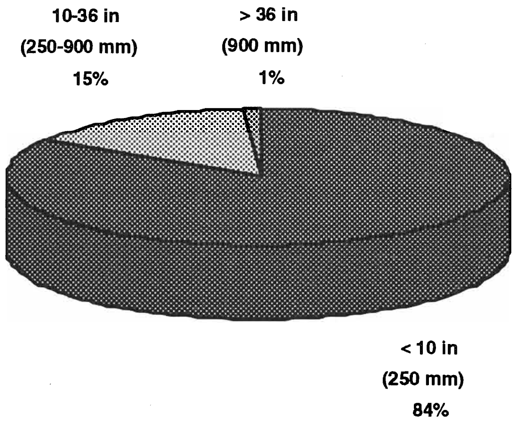


FIGURE 5 Distribution of nominal inside diameters of supply and sewage lines in North America.

Figure 6 is a basic classification system for trenchless methods used to install a wide range of types and sizes of new utility systems. The origins of the classification system are rooted in the Purdue University—Indiana DOT research project discussed in Chapter 1 (*3*). Modified versions of this classification system have been used in a technical paper for the American Society of Civil Engineers *Journal of Construction Engineering and Management* (*7*) and for a National Utility Contractors Association manual (*8*). This system has been accepted as a standard by both design and construction professionals. Other classification systems and detailed descriptions of the techniques can be found in the literature (*9–11*).

The classification system depicted in Figure 6 is based on a key principle of operation (i.e., whether the process requires people to be working inside the conduit as it is being installed underground.) If the process does require people to be inside the conduit, it is classified as either a utility tunneling (UT) operation or a pipe jacking (PJ) operation. If the process does not require people to be inside the conduit, it is classified as a horizontal earth boring (HEB) operation.

Table 1 provides a list of the basic trenchless alternatives identified in Figure 6, with a brief definition and description of each. Reading these descriptions is the initial step in determining which alternatives are compatible with a particular project's site conditions. Each of these methods is discussed in more depth in Chapters 3 through 8, and Chapter 9 summarizes the

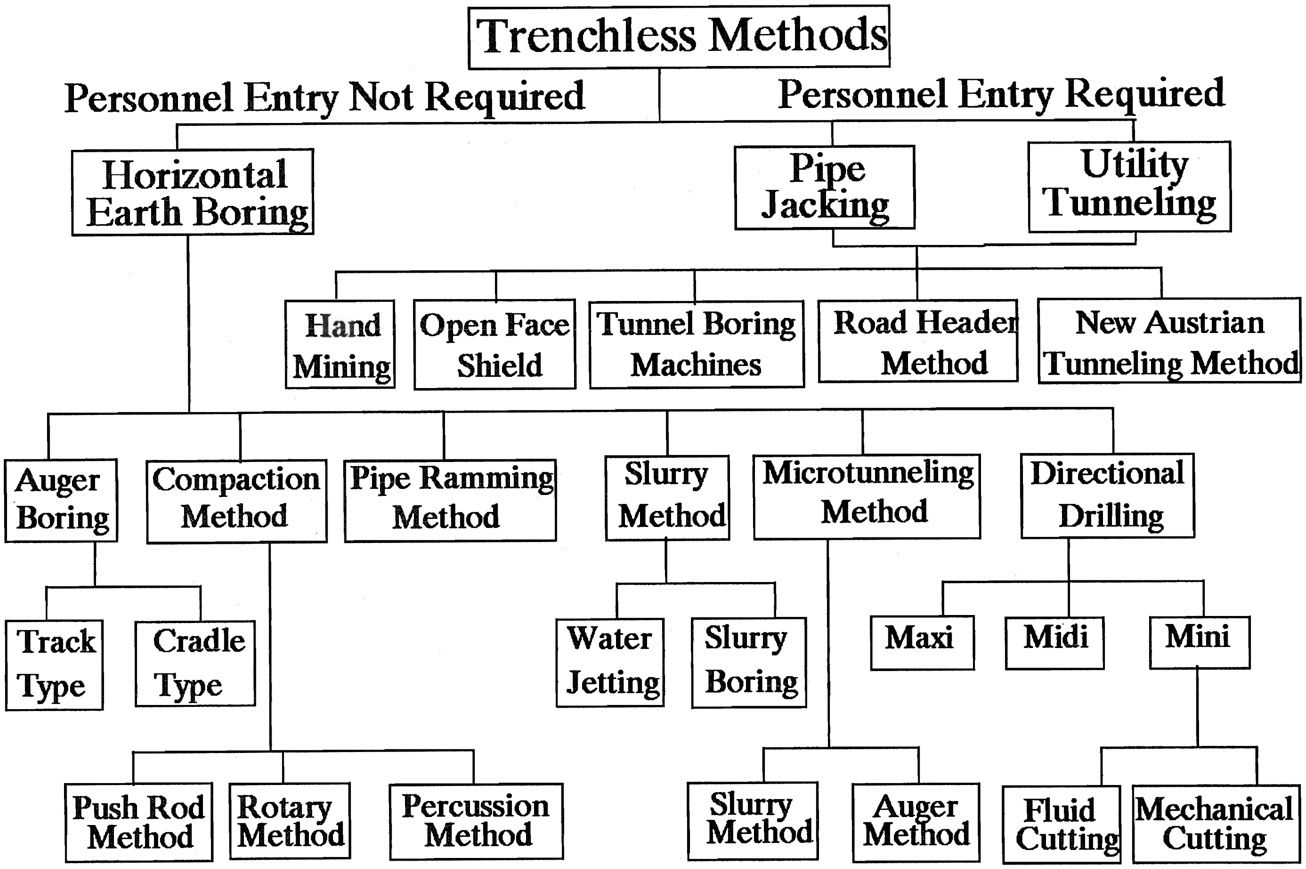


FIGURE 6 Classification systems for trenchless methods.

alternatives' characteristics. Table 2 provides some of the basic characteristics associated with the various trenchless alternatives. These, too, are described in more detail in Chapters 3 through 8 and are summarized in Chapter 9.

FACTORS AFFECTING THE SELECTION OF TRENCHLESS TECHNOLOGY ALTERNATIVES

During the planning, design, and installation phases of a trenchless technology (TT) project, it is important for decision makers be knowledgeable about the capability and limitations of TT alternatives. Constructibility issues need to be addressed early in the project planning and design phases.

The alignment, depth of cover, and profile of the utility may vary depending on the installation technique. It is important that the design provide the contractor with adequate surface and subsurface information so that compatible methods, materials, and equipment can be selected. Adequate information can only be provided if planning and design professionals are sensitive to and knowledgeable about constructibility issues.

Table 3 identifies significant factors that need to be evaluated during the selection of TT alternatives. Many of these factors are not significant for a traditional open-cutting (trench) technique, but are extremely important for a TT project. For example, a trenchless project in wet sand versus clay could require a different type of machine, whereas with a traditional excavation, the choice of machine might not be as important.

Figure 7 provides a flow diagram of a seven-step process for selecting a TT alternative suitable for a particular application. A more detailed discussion of each of these steps follows.

It is essential that construction input be provided during the selection of alternatives. For example, at what point should a steerable system be provided? A 15-m (50-ft) drive under a roadway in homogeneous soil conditions for nongravity sewer applications may need no steering, but steering may be required for a 90-m (300-ft) crossing.

Step 1: Develop an Understanding of Trenchless Technology Alternatives

Individuals involved in planning, designing, and constructing a TT project should have access to TT expertise. This can be accomplished by developing expertise within the state DOT's staff or by using a consultant. Keeping abreast of TT, which is constantly evolving, is a continuous learning process. Numerous trade and professional organizations (American Society of Civil Engineers (ASCE), NASTT, TTC, and NUCA) have conducted nationwide training programs. Trenchless

TABLE 1

DESCRIPTION OF TRENCHLESS CONSTRUCTION METHODS

Method Type	Method Description
I. Techniques Not Requiring Personnel Entry—Horizontal Earth Boring (HEB)	
Auger Boring (AB)	A technique that forms a bore hole from a drive shaft to a reception shaft by means of a rotating cutting head. Spoil is transported back to the drive shaft by helical wound auger flights rotating inside a steel casing that is being jacked in place simultaneously. AB may provide limited tracking and steering capability. It does not provide continuous support to the excavation face. AB is typically a 2-stage process (i.e., casing installation and product pipe installation).
Slurry Boring (SB)	A technique that forms a bore hole from a drive shaft to a reception shaft by means of a drill bit and drill tubing (stem). A drilling fluid (i.e. bentonite slurry, water, or air pressure) is used to facilitate the drilling process by keeping the drill bit clean and aiding with spoil removal. It is a 2-stage process. Typically, an unsupported horizontal hole is produced in the first stage. The pipe is installed in the second stage.
Microtunneling (MT)	A remotely controlled, guided pipe jacking process that provides continuous support to the excavation face. The guidance system usually consists of a laser mounted in the drive shaft communicating a reference line to a target mounted inside the MT machine's articulated steering head. The MT process provides ability to control excavation face stability by applying mechanical or fluid pressure to counterbalance the earth and hydrostatic pressures.
Horizontal Directional Drilling (HDD)	A 2-stage process that consists of drilling a small diameter pilot directional hole along a predetermined path and then developing the pilot hole into a suitable bore hole that will accommodate the desired utility and then pulling the utility into place. The HDD process provides the ability to track the location of the drill bit and steer it during the drilling process. The vertical profile of the bore hole is typically in the shape of an arc entrapping drilling fluid to form a slurry pathway rather than an open hole. This entrapped slurry provides continuous support to bore hole.
Pipe Ramming (PR)	A technique for installing steel casings from a drive shaft to a reception shaft utilizing the dynamic energy from a percussion hammer attached to the end of the pipe. A continuous casing support is provided and over excavation or water is not required. This is a 2-stage process.
Soil Compaction (SC)	This method consists of several techniques for forming a bore hole by in-situ soil displacement using a compacting device. The compacting device is forced through the soil, typically from a drive shaft to a reception shaft, by applying a static thrust force, rotary force and/or dynamic impact energy. The soil along the alignment is simply displaced rather than being removed. This is a 2-stage process.
II. Techniques Requiring Personnel Entry	
Pipe Jacking (PJ)	A pipe is jacked horizontally through the ground from the drive shaft to the reception shaft. People are required inside the pipe to perform the excavation and/or spoil removal. The excavation can be accomplished manually or mechanically.
Utility Tunneling (UT)	A 2-stage process in which a temporary ground support system is constructed to permit the installation of a product pipe. The temporary tunnel liner is installed as the tunnel is constructed. The temporary ground support system can be steel or concrete tunnel liner plates, steel ribs with wood lagging, or an all wood box culvert. People are required inside the tunnel to perform the excavation and/or spoil removal. The excavation can be accomplished manually or mechanically.

Technology, Inc., publishes a TT magazine, the *No-Dig Engineering Journal*, and sponsors a wide range of annual TT seminars. NASTT sponsors a no-dig convention each year, complete with presentations, published proceedings, and exhibits. In addition, there are numerous books and manuals, many of which are included in the reference section of this synthesis.

TT expertise requires an understanding of the benefits provided by TT and the performance characteristics of the techniques (i.e., what methods are appropriate for a given set of conditions). Most of this synthesis addresses construction issues; however, the following itemizes some social and environmental benefits that could be included in the selection process (*12*).

Public Impact

Traffic—Is it important to minimize disruption to traffic? In some cases, use of TT results in minimum or no interference with traffic. Pedestrian and vehicular traffic concerns made the Boston Water and Sewer Commission decide to use TT for a sewer replacement/rehabilitation project on St. James Avenue in downtown Boston (*13*). Because traffic impact is a major concern for many projects, shaft location should be considered carefully during the design phase to identify locations where traffic impact will be minimized. For example, if a drive shaft is located in a main intersection, it could have a significant impact on traffic because it may be in use for several months.

TABLE 2

CHARACTERISTICS OF TRENCHLESS CONSTRUCTION METHODS

Type[a]	Pipe/Casing Installation Mode	Suitable[b] Pipe/casing	Soil Excavation Mode	Soil Removal Mode
AB	Jacking	Steel	Mechanical	Augering
SB	Pulling/Pushing	All Types	Mechanical and Hydraulic	Hydraulic, Mechanical Reaming and Compaction
MT	Jacking	Steel, RCP, GFRP, PCP, VCP, DIP	Mechanical	Augering or Hydraulic (Slurry)
HDD	Pulling	Steel, PVC, HDPE	Mechanical and Hydraulic	Hydraulic, Mechanical Reaming and Compaction
PR	Hammering/Driving	Steel	Mechanical	Augering, Hydraulic, Compressed Air, or Compaction
SC	Pulling	Steel, PVC, HDPE	Pushing	Displacement (in-situ)
PJ	Jacking	Steel, RCP, GFRP	Manual or Mechanical	Augers, Conveyors, Manual Carts, Power Carts, or Hydraulic
UT	Lining	Steel or Concrete Liner Plates, Ribs w/ Wood Lagging, Wood Box	Manual or Mechanical	Augers, Conveyors, Manual Carts, Power Carts, or Hydraulic

[a] AB–Auger Boring; SB–Slurry Boring; MT–Microtunneling; HDD–Horizontal Directional Drilling; PR–Pipe Ramming; SC–Soil Compaction; PJ–Pipe Jacking; UT–Utility Tunneling.

[b] Steel–Steel Casing Pipe, RCP–Reinforced Concrete Pipe, GFRP–Glass-Fiber Reinforced Plastic Pipe, PCP–Polymer Concrete Pipe, VCP–Vitrified Clay Pipe, DIP–Ductile Iron Pipe, PVC–Polyvinyl Chloride Pipe, HDPE–High Density Polyethylene Pipe.

In such a case, open-cutting may reduce traffic impact because the crossing could be completed in less time.

Pavement—Pavement cutting, followed by the usual quality of restoration, may significantly reduce pavement life. This results in more frequent pavement repairs, additional traffic impacts, and increased maintenance costs (*14*). In a study conducted for the city of Burlington, Vermont, it was determined that "streets without utility cut patching have a life of 18.5 years while streets with utility cut patching have a life of 10.9 years" (*15*). The use of TT alternatives may result in no or minimal pavement cuts, primarily for shafts. However, field construction problems could lead to major pavement cuts under emergency conditions. Proper site investigation, planning, design, and selection and use of compatible construction methods, materials, and equipment can minimize these types of problems.

Commercial—Are there businesses along or near the work area that will suffer significant losses because of lane or road closures? With proper planning and design, use of TT could minimize commercial impact.

Residential—Is it important to minimize delays, inconvenience, and congestion in the daily lives of residential customers? Is it important to provide access for emergency services? Is it important that yards, driveways, and sidewalks not be disturbed? Residential customers of River Oaks, in Houston, Texas, thought these factors were extremely important, and because of their demands, 7,000 m (20,000 ft) of gravity sewer lines ranging from 250 mm (10 in.) to 530 mm (21 in.) in diameter were installed by microtunneling (MT) in 1987 (*16,17*). The city of Houston was so impressed that MT has become the standard sewer main installation technique for lines installed deeper than 8 m (25 ft). Approximately 40 percent of all microtunneling work in the United States has been performed in the city of Houston.

Government Income—What is the potential for decreased sales tax revenue (even parking meter revenue should not be overlooked) if businesses suffer a loss or go bankrupt because of the impact of installing conduits beneath roadways? With proper planning and design, trenchless installation methods could result in unimpeded traffic flow, with negligible financial loss.

Accidents—Often, when TT is used, the number of workers is reduced, but the workers are more specialized. Specialized workers can reduce the risk of accidents to project personnel. Also, when TT is used to minimize traffic disruption, the risk of accidents involving the public may be reduced.

Environmental Impacts

Noise—During TT projects, most major activity takes place underground. The problem of surface noise can be isolated to access shafts where it can be managed to acceptable levels (e.g., by use of hospital-type generators).

Air Pollution—How sensitive is the area to fine soil particles being dispersed in the air as a result of soil excavation, handling, and backfilling? This can be an important issue for projects near hospitals. With proper planning and design, the

TABLE 3

FACTORS AFFECTING THE SELECTION AND USE OF TRENCHLESS TECHNOLOGY (TT) ALTERNATIVES

Factors	Description
Diameter of Drive	Need to identify which methods are suitable to install the pipe required for the drive from project scope. As the diameter increases, the complexity and risks associated with the project also increase. Some methods are unsuitable for some diameters.
Length of Drive	Need to identify which methods are suitable for installing the pipe for the drive lengths required by the project scope. As the length increases, the complexity and risks associated with the project also increase. Length of drive may rule out certain methods or result in cost penalties for mobilization for short distances.
Existing Underground Utilities	Need to determine location of all existing underground utilities and underground structures so that the likelihood of obstruction or damage can be addressed for each TT alternative. Actions needed to avoid obstructions should be identified for each prospective method.
Existing Above Ground Structures	The likelihood of ground movement caused by the proposed TT alternatives should be evaluated. A possibility of heaving the roadway or causing ground subsidence should be evaluated. The parameters to be monitored to ensure minimum effect on adjoining structures must be identified.
Obstructions	The likelihood of encountering obstructions (either naturally occurring or manmade) should be evaluated. The proposed equipment must be able to handle the anticipated obstructions. For example, some techniques might permit steering around or crushing obstacles up to a certain size.
Casing	Is a casing pipe required? Or, can the product pipe be installed directly? If a casing pipe is required, does the annular space between the product pipe and casing pipe need to be filled? If so, with what materials? Does the casing pipe need to have internal and/or external coatings? What distance should the casing extend beyond the pavement edge?
Soil Conditions	Need to accurately determine the actual soil conditions at the site. Is the proposed TT equipment compatible with the anticipated soil conditions? Where is the water table? Can the equipment operate properly under the water table? Can the equipment function in unstable ground conditions? Or, will the soil conditions need to be stabilized prior to the trenchless process being employed? If so, how? For example, will the soil need to be dewatered? Is dewatering reasonable at the specific project site? Are contaminated soils or groundwater anticipated? What is the likelihood of ground heaving or settlement? Need to establish allowable limits for ground movement and need to determine how ground movement will be measured.
Drive/Reception Shafts	Need to make sure that adequate space is available at the project site to provide the required space for the shafts. The working room available may limit the length of pipe segments that can be handled. For example, using 12 m (40 ft) steel pipe segments will minimize field welding time and may be desirable from a construction perspective, but may not be achievable due to site constraints. These constraints need to be identified early in the process.
Accuracy	Need to determine alignment and grade tolerances desired for the installation. Typically, the tighter the tolerance, the higher the cost of installation will be. How will this level of accuracy be measured?
Steerability	What level of sophistication is needed to track the leading edge of the cutting head and being able to steer it? If the system gets off line and grade, what limits need to be placed on corrections to prevent overstressing the drill stem or pipe?
Bulkheads	Bulkheads are used to provide end seals between the casing and product pipe. Need to determine if they should be required. If so, what should they be made of?
Materials	Need to determine what materials the casing and/or product pipe should be (i.e., Steel, RCP, PVC, GFRP, HDPE, etc.) and joint requirements. Selection must be based on use, environmental conditions, and compatibility with the trenchless method.
Ventilation/Lighting	Under what conditions will ventilation and/or lighting be required. How will adequate ventilation and lighting be determined?
Abandonment	Under what conditions should the work be stopped and the line abandoned. What will be the abandonment procedures?
Measurement/Payment	How and who will determine the measurement by which the contractor will be compensated? What are the conditions of payment?
Submittals	What information is going to be required for the contractor to supply? Who will review the submittal information? What are the qualifications of the reviewers? What are the construction risks and who will accept these risks (contractor or owner)?

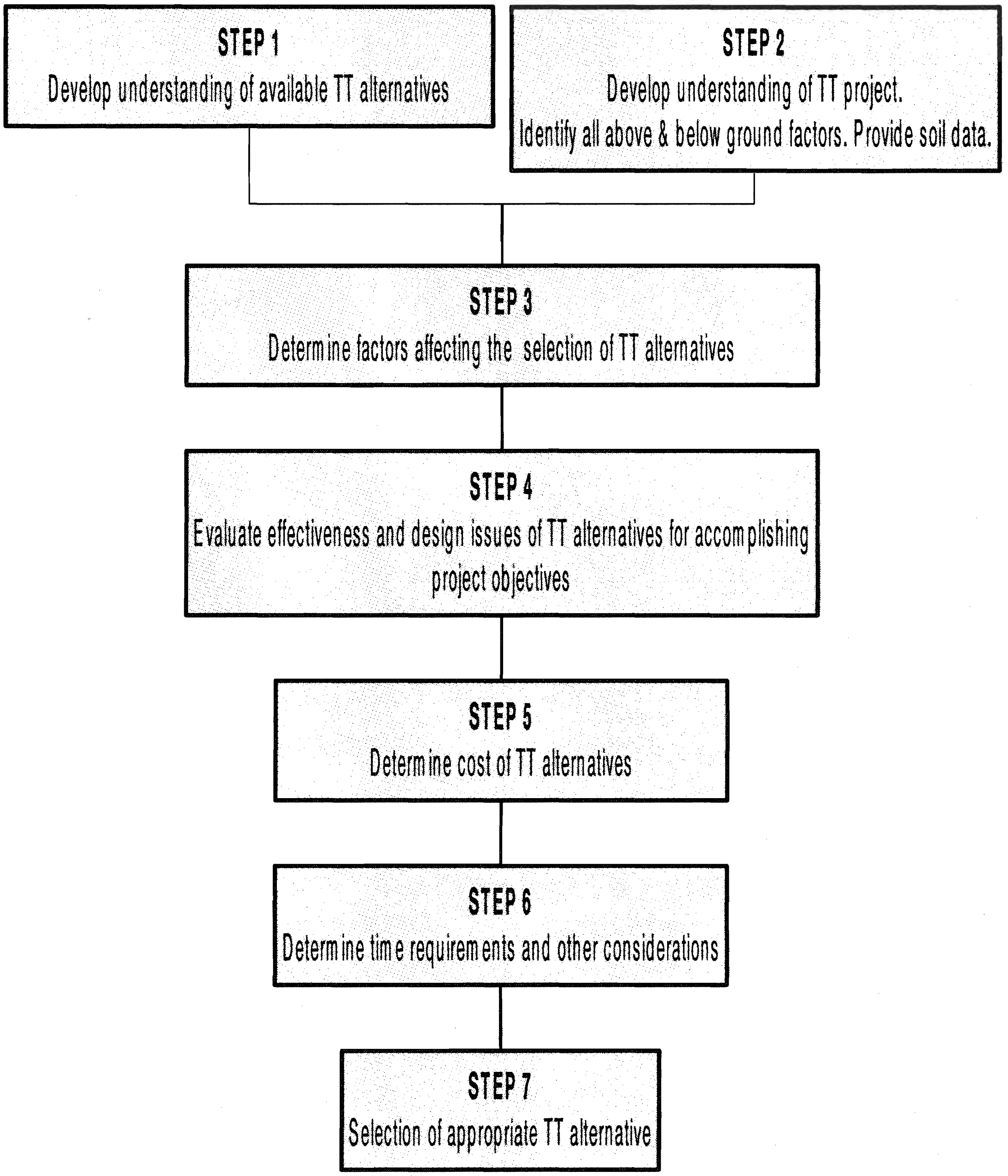


FIGURE 7 Trenchless technology (TT) selection process.

use of TT can limit the potential for airborne particles by minimizing the amount of excavation. The location of the excavation can be controlled by locating the shafts as far away as possible from sensitive areas.

Soil Disposal—The handling and disposal of hazardous and contaminated materials is a serious and expensive issue, requiring special equipment and specially trained personnel. Will the project involve disposal of excavated asphalt concrete? Will the project require disposal of chemically contaminated soil or soil contaminated with sanitary sewer exfiltration?

The use of TT alternatives can minimize the volume of contaminated soil and groundwater that needs to be disposed of or treated. For example, when 915 m (3,000 ft) of relief sewer 1,372 mm (54 in.) was installed parallel to the Nimitz Highway for the city and county of Honolulu, Hawaii, soil contaminated with oil was extensive. The contractor stated that with microtunneling, only soil equal to the volume of pipe had to be dug out and that only the slurry had to be treated (*18*).

Shaft location and design are important in contaminated areas. Often it is possible to keep shafts out of contaminated zones. By using watertight shaft construction techniques, the risks associated with the removal, disposal, treatment, and migration of contaminated materials can be minimized.

Surface Defacement—To what extent will grass, trees, wetlands, and other environmental components be affected by the proposed methods? With TT use, this impact can be minimized.

Step 2: Develop an Understanding of the Trenchless Technology Project

DOT personnel involved in the planning, design, and installation of a TT project must develop a clear understanding of the characteristics of a particular project. These individuals must be able to identify aboveground and underground factors that will affect the complexity of the project and will be significant in the selection of the proper TT equipment. This requires that adequate soil data be provided.

The importance of adequate soil information cannot be overemphasized. The TT contractor must navigate through soil without seeing the excavation and conduit installation process. In addition, the contractor must be informed of anticipated soil conditions to select the proper equipment and design the proper installation process. The contractor should not be expected to be a geotechnical engineer.

ASCE recommends the use of Geotechnical Design Summary Reports (GDSRs) (*19*). Nothing can eliminate the risk of encountering differing subsurface conditions. However, the potential for costly disputes and litigation over what constitutes differing conditions can be greatly reduced, if not eliminated, with well-defined geotechnical baselines. The overall risk associated with an underground project is inversely proportional to the extent of subsurface investigation. The GDSR sets forth the geotechnical conditions anticipated by the designer and establishes clear and concise baselines for identification of differing site conditions. The GDSR should be incorporated as part of the contract, with no exculpatory language disclaiming responsibility for accuracy or completeness. The ASCE Underground Technology Research Council (UTRC) is in the process of developing a stronger position on this recommendation. The UTRC expects to publish a manual of practice on the use of GDSRs in 1997.

Soil information needed for construction may differ from what is needed for design. The civil engineering design community typically uses the Unified Soil Classification System (USCS), which was developed for the U.S. Corps of Engineers by Casagrande in 1953 and adopted by the American Society for Testing and Materials (ASTM) in 1969. The owner (i.e., a DOT or utility) must provide adequate soil information to the contractor. This information should not be limited to USCS data. The contractor is more concerned with the behavior of the soils; therefore, soil information should be communicated to the TT contractor, with terms and concepts clearly explaining characteristics and anticipated behavior.

The tunneling industry uses soil classification terms that are different from those a TT contractor typically relates to (*5, 20*). The tunneling contractor is concerned with the behavior of the soil at the tunnel face. The terms commonly used in the tunneling industry are (1) running ground, (2) flowing ground, (3) raveling ground, (4) squeezing ground, and (5) swelling ground (*21,22*).

TT contractors are more familiar with soil classification terms such as (1) wet running sand; (2) wet stable sand; (3) dry sand; (4) dry clay; (5) wet clay; (6) soil with small gravel; (7) soil with large gravel, cobbles, and boulders; (8) hard pan; (9) soft or hard rock; and (10) fill and mixed face conditions (*4,5*). Numerous references provide detailed information on the criteria for providing adequate subsurface information (*10,11,21–24*).

Table 4 contains three categories of roadways based on the relative priority level of the traffic. Numerous methods of classifying roadways exist (*1,3*). The objective of the roadway classification system is to emphasize that road use affects the complexity of a project. Higher traffic volumes and higher rates of speed increase the risk to the public if a construction failure occurs. The requirements and specifications suitable for an urban roadway probably will be inadequate for a fully access-controlled highway.

Step 3: Determine the Factors Affecting the Selection of Trenchless Technology Alternatives

After Steps 1 and 2 are accomplished, individuals should have a clear understanding of the capability and limitations of available TT options and a clear understanding of the nature of the project. The objective in Step 3 is to direct more attention to the appropriate method for a particular project. Table 3

TABLE 4

THREE TYPES OF ROADWAY SYSTEMS

Type	Description
Fully Access-Controlled Highways	Includes federal-aid Interstate freeways, expressways, and other primary highways where undisrupted traffic and highway integrity are of ultimate priority. No pavement cutting is allowed, and parallel utility installation is normally prohibited. Normally, there is wide open space within the right-of-way (ROW).
Limited Access-Controlled Highways	Includes state highways and major local, county, and municipal roads which experience medium traffic volume. Pavement cutting might be permitted on some occasions. Parallel utility installation is generally allowed but not under pavement. Wide ROW space is often available.
Urban Roads and Streets	Might experience above and below ground congestion. The indirect and social costs of utility projects could be significant. Working space is usually limited. Partial traffic lane closure is normal. Parallel utilities can be under either the sidewalks or roadway pavements.

contains a list of factors that can affect the selection of TT alternatives. Once the conditions of a specific site are known, these factors can be evaluated. For example, casing under roadways is not always required. Therefore, the need for casing needs to be determined because it could have a significant impact on the complexity of the project.

In general, state regulations require encasement of mains that cross under pavement. However, DOTs are not unified on this policy. About one-third of the states require encasement of all types of line crossings, whereas two-thirds allow crossings without encasement under certain conditions (*1*).

Reasons for requiring encasement include the following:

- To avoid roadway excavation for repair or replacement of the pipeline,
- To ensure structural integrity of the roadbed and pipeline, and
- To detect and remove leaking fluids and gases from the vicinity of the pipeline with proper venting.

Following are reasons for not requiring encasements:

- It is more difficult to protect the pipeline from corrosion, and
- Procedures have been developed that ensure adequate wall strength in the pipeline to handle anticipated stresses.

The Gas Research Institute (GRI) has published guidelines and personal computer software to evaluate actual and allowable stresses for pipeline crossings under a highway. This information may be useful in determining the need for casings (*25–29*).

Step 4: Evaluate the Effectiveness and Design of Trenchless Technology Alternatives

After determining which factors apply to a specific project, each TT alternative should be evaluated to determine compatibility and to identify any special conditions. For example, installing a 600-mm (24-in.) steel casing that is 16 m (50 ft) in length under a roadway in firm silty sand may not require the use of locating equipment and a steering head for the leading end of the casing. However, if the crossing is 100 m (300 ft) in length, the locating and steering capability should be specified. This option should not be left up to the contractor. Otherwise, the knowledgeable and prudent contractor will bid knowing that it is important to know where the end of the steel is at all times, but his or her bid will be higher than the contractors who elect to risk public safety to obtain a lower bid. If left to chance, the probability of field emergencies during construction will be high.

Step 5: Determine the Cost of Trenchless Technology Alternatives

After the appropriate TT alternatives have been determined based on technical capabilities, the cost-effectiveness of the alternatives should be analyzed. The need to evaluate the total and life-cycle costs of a utility project has been adequately addressed in the industry (*30–32*). The total project construction cost is the sum of all real costs incurred as the direct or indirect result of the project. The life-cycle cost takes into consideration the total construction cost and the operation and maintenance cost incurred during the life of the project.

It is a common practice for TT alternatives to be selected based on the lowest direct cost only (i.e., the lowest qualified bidder). This practice is being evaluated by some DOTs. For example, Minnesota DOT has completed a study, *Indirect Costs of Utility Placement and Repair Beneath Streets*, which emphasizes that "the purpose of an analysis of indirect cost of utility work is to minimize the total economic costs to the community as a whole. In a situation where the indirect costs are significant, the method of work which is most cost-effective for the community as a whole may not be the method with the lowest first cost. Basing the selection of construction technique on both direct and indirect costs does not increase the total cost to the community of the project. Instead, it avoids one segment of the community being unfairly penalized with the imposition of the social costs while another group pays less than the true cost of the work" (*33*). For example, pavement cuts decrease the service life of the pavement and increase operation and maintenance costs. These costs may not be reflected in the direct construction cost, but the community will eventually have to pay the extra cost for pavement repairs and replacement. Typically, the procedure to address social costs is simply for the owner to limit the options that can be proposed by bidders to those that will result in acceptable social costs. This approach avoids the necessity of quantifying social costs, which is very difficult.

The following list of possible costs that could be significant for selecting methods to install utilities beneath roadways were taken from the Minnesota study (*33*), which is based on the work of the Institute of Science and Technology at the University of Manchester in the U.K. (*34*).

Direct cost is the amount of money the owner pays for items that are necessary for, or are a direct result of, accomplishing the project. Direct costs include the following:

- Permit and easement
- Site investigation
- Legal and administrative
- Project engineering
- Field construction (original bid amount plus change orders)
    - –Excavation and backfill
    - –Pipe and pipe installation
    - –Pavement reinstatement
    - –Temporary utility service diversions
    - –Traffic diversions and traffic control
    - –Treatment of contaminated soils, slurry, and groundwater.

Indirect cost is the real cost incurred as an indirect result or impact of the construction operation on the normal service and operation of public and private facilities in the vicinity of the project area. Typical items in this category are as follows:

- Traffic
  - Traffic diversions and delays
  - Increase in vehicle operating costs
  - Loss of accessibility and parking spaces
  - Delays to public transport
- Environmental
  - Increased noise
  - Increased air pollution
  - Increased construction debris
  - Increased visual intrusion
- Safety
  - Decreased safety for motorists
  - Decreased safety for pedestrians
- Economic
  - Loss of trade to local businesses
  - Damage to other utilities
  - Damage to street pavement
  - Increased workload on other government agencies or utilities
- Service Life
  - Decreased live and dead loads on the pipe, resulting in the likelihood of extended service life
  - Increased pipe quality as a result of construction load requirements, resulting in the likelihood of extended service life.

The cost of public transport disruption can be further broken down as the cost of the following:

- Additional route mileage
- Delay time
- Shuttle/relief
- Extra walk time
- Information and inspectors' time
- Loss of revenue
- Impact of bus traffic on diversion routes.

Developing an economic model that accurately addresses all direct and indirect costs is difficult and time-consuming. Several articles exist in the literature that address this need and provide recommendations on how to develop a practical cost model (*9,10,31,33,35–37*).

Step 6: Determine Time Requirements and Other Considerations

After the cost-effective, appropriate TT alternatives have been identified, the next step is to determine a construction schedule for the project. This schedule should include the following:

- Time to make necessary modifications to the equipment
- Mobilization requirements
- Project set-up time
- Time required to construct shafts
- Time required to install the conduit
- Time required to remove the equipment
- Demobilization.

Step 7: Selection of the Appropriate Trenchless Technology Alternative

The appropriate TT alternative is the one that provides the highest probability of success. Following are criteria for a successful project:

- Ensuring the safety of workers, the public, and property
- Providing the required quality end product
- Minimizing the impact to society and the environment
- Meeting time requirements
- Meeting budget requirements.

CHAPTER THREE

AUGER BORING AND SLURRY BORING

Auger boring (AB) and slurry boring (SB) are the two most commonly used trenchless technology (TT) methods for installing steel encasements beneath roadways. Both have been used in the United States for more than 50 years. Each method is unique and will be discussed separately in this chapter.

AUGER BORING

AB is a technique for forming a horizontal bore hole through the ground, from a drive shaft to a reception shaft, by means of a rotating cutting head. The cutting head is attached to the leading end of an auger string. Spoil is transported back to the drive shaft by the rotation of helical-wound auger flights within the steel casing pipe. Steering capability varies from none to full vertical control. Vertical control, using a water level, is typical. Horizontal control is uncommon.

It is possible to use AB equipment to construct an uncased bore hole by using a cutting head and auger. However, this practice results in an unsupported hole, and the unprotected augers rotating in the drive shaft create special hazards for workers. Therefore, common practice is to simultaneously jack the steel casing with the boring operation. If uncased AB is permitted, it should be limited to soil conditions with sufficient stand-up time and short, small diameter bores. In general, this practice should not be encouraged, because of hazards.

Description

The two major types of AB systems are (1) track-type and (2) cradle-type. The basic components of a track-type system are the track system, boring machine, casing pipe, cutting head, and augers. Optional components include a casing lubrication system, steering system, locating system, and casing leading-edge band. The auger driving device and jacking equipment usually are integrated into the boring machine.

The auger string consists of one or more augers connected end to end for the full length of casing pipe. The leading end of the string is connected to the cutting head, and the other end is attached to the auger machine. The machine applies torque to the auger string, which in turn rotates the cutter head. The casing is advanced by hydraulic jacks located at the rear of the machine. The casing pipe, augers, and cutting head are propelled forward, resulting in continuous and simultaneous soil excavation, spoil removal, and casing installation.

A properly constructed drive shaft is important for the success of a track-type AB project. The shaft requires a stable foundation and adequate thrust block. The foundation must support the tracks, permitting the machine to move forward and backward without vertical movement. The track system must be placed on the same line and grade as the desired bore hole. If the track foundation settles, accuracy will be affected and binding forces could result within the bore hole. Often this foundation will require crushed stone or concrete.

The thrust block transmits the horizontal jacking forces from the tracks to the ground at the rear of the drive shaft. The thrust block must be designed to distribute the jacking force over sufficient area so that the allowable compressive strength of the soil is not exceeded. If the thrust block fails or moves, bore hole accuracy will be compromised and binding forces could result within the bore hole.

The track-type AB operation involves the following:

- Constructing the shaft, complete with foundation and thrust block;
- Placing tracks on the foundation;
- Placing the AB machine on the tracks;
- Placing the casing with the auger inside, between the front of the shaft and machine;
- Installing the cutting head; and
- Attaching the auger and casing to the machine.

When the setup is complete, jacking and boring of the first casing segment begins. Figure 8 illustrates the installation of the first segment of jacking pipe by the track-type AB method. Figure 9 is an example of an actual track-type AB field setup. The excavated material is ejected from the machine in the shaft. When the first casing segment is installed, the casing and auger are disconnected from the machine and the machine is moved to the back of the pit. The next casing and auger segment are placed in the shaft, connected to the previous casing and auger segment and to the machine. This process is repeated until the installation is complete.

Cradle-type AB involves the excavation of the bore hole and the installation of the casing in a manner similar to track-type AB. Cradle-type AB, which is not as common as track-type, is limited primarily to oil and gas pipeline crossings with sufficient rights-of-way. Drive shaft construction is not a critical component of the process because the machine and casing/auger system are held in suspension by construction lifting equipment. The machine is actually attached to the end of the casing. A cable, winch, and jacking lug (dead man) provide the propulsion force necessary to drive the cutting head and casing through the ground.

The complete AB system can be assembled aboveground. All casing segments are usually welded together in one unit before boring commences so that the installation process can be accomplished in a continuous operation. This requires extended preparation time, but minimizes boring time. Workers are not required to enter the shaft because the operator rides on

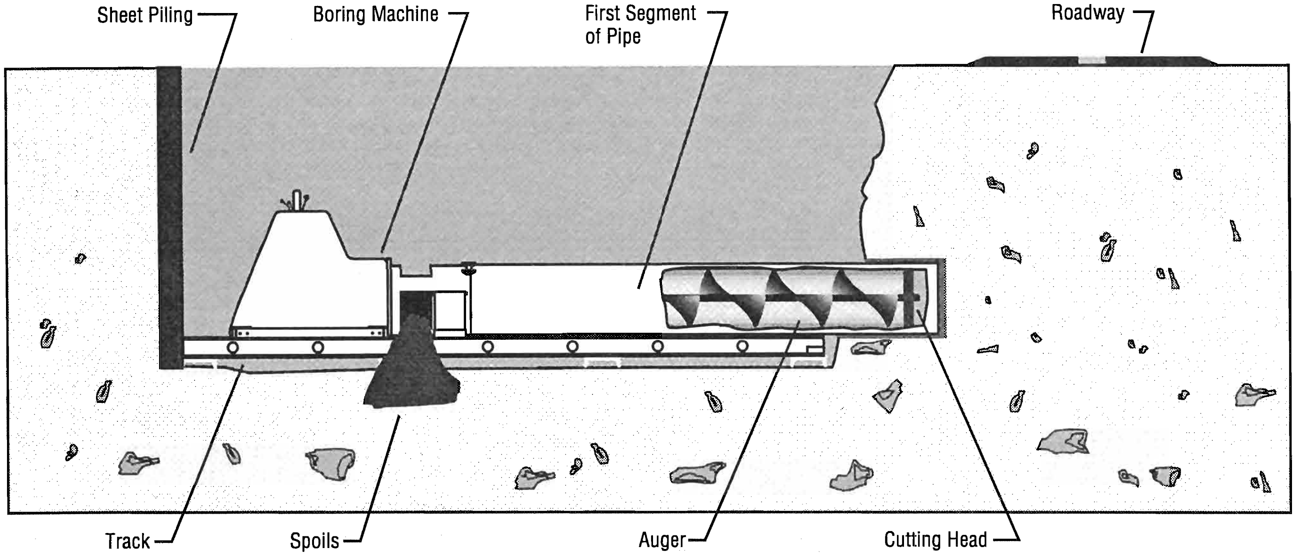


FIGURE 8 Installation of casing with track type auger boring method.

FIGURE 9 Actual field setup of the track type auger boring method.

the machine, which is attached to the casing. Figure 10 illustrates a typical setup for a cradle-type AB operation. Figure 11 is an example of an actual cradle-type AB field setup.

Main Features and Application Range

Type of Casing

Because the augers rotate inside the pipe, the pipe and coating material must resist potential damage caused by rotating augers. Therefore, the typical casing pipe is made of steel. The product or carrier pipe installed inside the casing can be made of any material suitable for the product being carried (*3,7,8*).

Diameter Range

AB can be used to install casing pipe ranging from 100 mm (4 in.) to at least 1,500 mm (60 in.) in diameter, with the most common diameters ranging from 200 mm (8 in.) to 900 mm (36 in.) (*3,7,8*).

Length of Bore

The longest continuous track-type AB project is 270 m (886 ft). However, typical project lengths range from 30 m (100 ft) to 91.5 m (300 ft), with the demand for longer installations increasing.

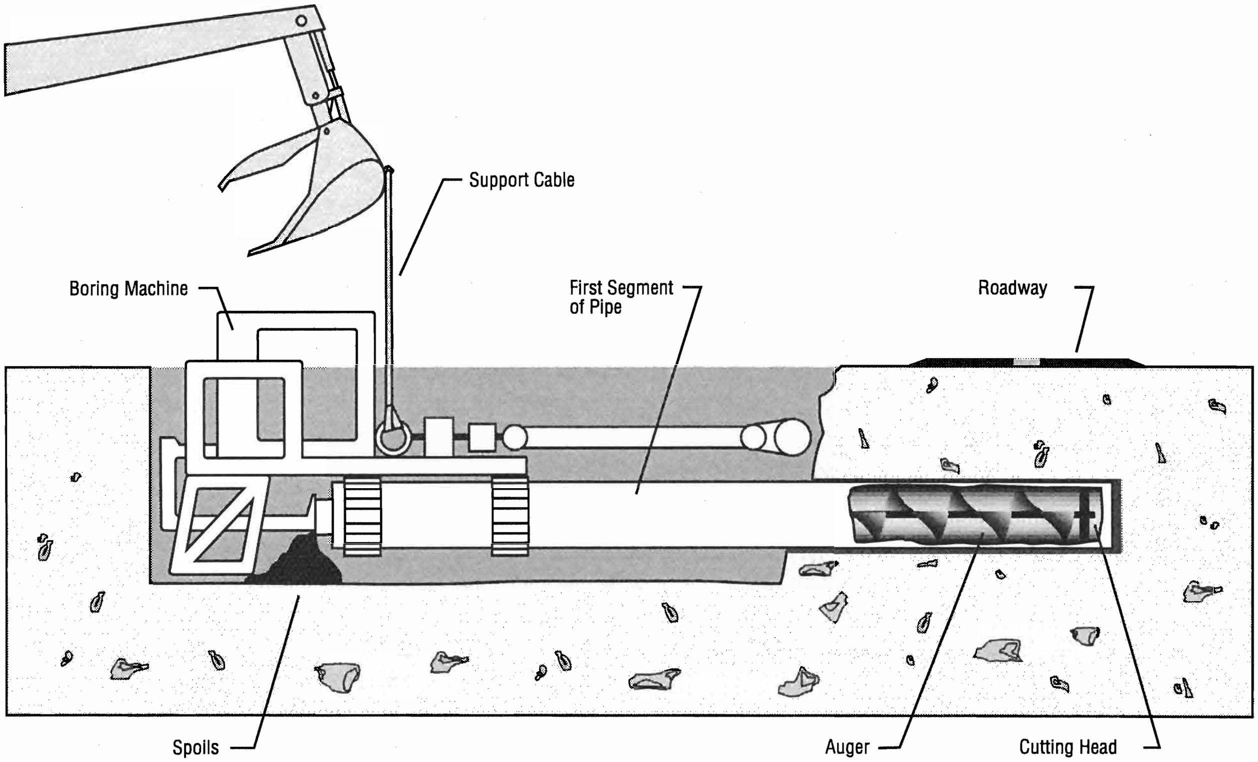


FIGURE 10 Installation of casing with cradle type auger boring method.

FIGURE 11 Actual field setup of the cradle type auger boring method.

Ground Movement

With proper equipment selection and operation, the probability of ground subsidence and heaving can be minimized. Subsidence occurs over the casing being installed when overexcavation is permitted, and heaving occurs when excessive force is applied to the excavation face. Subsidence is the most common problem. The major factors that result in overexcavation are as follows:

- The diameter of the bore hole being excavated by the wing cutters, which are attached to the cutting head, is excessive, leaving an annular space between the bore hole and casing outside diameter that is too large. Typically, the diameter of the bore hole should be 25 to 50 mm (1 to 2 in.) larger than the outside diameter of the casing pipe.
- Soil is allowed to enter the end of the casing. If this condition remains unchecked and uncorrected, loss of ground will result, which will be manifested at the ground surface in the form of a sinkhole.

Subsidence can occur soon after over-excavation with noncohesive soils or later after overexcavation with cohesive soils. The most important factor in preventing subsidence and heave conditions is the operator's skill. An experienced operator will know what to do when the unexpected happens. For example, if soil changes from cohesive to noncohesive, an experienced operator will know to adjust the location of the cutting head inside the casing to avoid removing too much soil.

Required Working Space

Shafts are required at both ends of the casing. The drive shaft is the primary working shaft. The size of the shaft is determined by the diameter of the bore hole and the length of the casing segments to be used. Typically, casing segments are 3.0 m (10 ft), 6.1 m (20 ft), or 12.2 m (40 ft) in length; the most common length is 6.1 m (20 ft).

If casing segments 6.1 m (20 ft) in length are used, the shaft size will be 9.1 m (30 ft) to 10.7 m (35 ft) in length by 2.5 m (8 ft) to 3.6 m (12 ft) in width. The surface area should be approximately 23 m (75 ft) by 46 m (150 ft). The absolute minimum surface area should be 9 m (30 ft) by 25 m (82 ft).

Operator Skill

The basic operation of an AB machine is straightforward. Jacking thrust and torque are the most critical parameters to control. Nevertheless, most AB projects require experienced and skilled operators because the operators are not able to see the excavation and spoil removal process. Much of the work must be done by "feel." Operators must be alert at all times so that they recognize changing conditions and decide quickly what corrective action must be taken. They also need to know how to check line and grade and take corrective action.

Accuracy

If a steering head is not used in the AB system, accuracy depends on groundwater conditions, length of drive, initial setup, and operator skill. If a grade control steering head is used with a water-level grade monitoring system, the grade can be maintained within 13 mm (0.5 in.) throughout the bore length if checked at 0.61-m (2-ft) intervals.

Alignment is the most difficult steering component to control; however, a steering head that permits horizontal and vertical corrections is available. The horizontal directional control is able to keep the leading end of the steel casing within 150 mm (6 in.) if checked at 0.61-m (2-ft) intervals. In general, an accuracy of 1 percent of the length of the bore can be achieved.

Recommended Ground Conditions

AB can be used in a wide range of soil conditions, from wet sand to firm dry clay to solid rock. Firm sandy clay is the most compatible soil condition for using this method. Boulders or cobbles as large as one-third of the casing diameter can be accommodated. Table 5 illustrates a wide range of soil types and the procedures that should be used with each to ensure a successful project. For example, wet sand can be auger bored by pulling the augers back in the casing several feet and compressing a plug of soil in front of the casing to prevent soil from flowing through the casing. However, the operator should be able to recognize when flowing sand is uncontrollable. Sand flowing through the casing is dangerous because overexcavation is inevitable, resulting in subsidence.

For hard rock conditions, a two-pass variation in AB facilitates the use of drill stems with water. The casing is installed after the pilot hole formed by the drill stem is reamed.

Cost

The cost of AB is determined by numerous factors. Typical costs are provided in Table 10 in Chapter 9.

Productivity Issues and Special Concerns

Horizontal AB typically is accomplished by specialized subcontractors. Often the drive and reception shafts are constructed by the prime contractor. It is important that the drive shaft construction crew understand that the success of the project depends to a large extent on the quality of the drive shaft. For this reason, some AB contractors insist on constructing their own shafts. Shaft construction may take 1 day for shafts less than 3 m (10 ft) when the excavation embankments can be sloped. Shaft construction could take several weeks if the shaft is greater than 10 m (33 ft) and the excavation support system is steel sheet piling.

Once the drive shaft is constructed, it will take a four-person crew 3 to 4 hr to set up the AB equipment for a steel casing project 610 mm (24 in.) in diameter utilizing segments 6.1 m (20 ft) in length. A typical production rate for this size project is 33 m (100 ft) in an 8-hr shift. This includes the complete cycle time (i.e., actual penetration rate and casing welding time). Depending on soil conditions and casing diameter and length, AB typically takes place at a rate of 1 to 12 m/hr (3 to 40 ft/hr) (*10*).

Because AB is executed from a drive shaft, there is no theoretical maximum depth. The primary cost increase results from the cost of the extra shaft. The minimum depth for cohesive soils is approximately 0.61 m (2 ft). For noncohesive soils, the minimum depth is approximately 1 m (3.3 ft).

Production rates for AB vary significantly, depending on the optional equipment used by the contractor. For example, the use of horizontal and vertical control steering heads and locating equipment requires more time. The use of bentonite lubricant on the external wall of the casing pipe is time-consuming and can be messy. However, these practices can help ensure a successful AB project.

Transportation Agency Practice

AB is permitted in all states by DOTs. Survey responses indicate that most states do not have AB specifications, and for those that do have them, they are often too general. The Texas DOT specification, covered in Item 476—Jacking, Boring or Tunneling Pipe, is typical. It states "When the auger method is used, a steel encasement pipe of the appropriate diameter equipped with a cutter head to mechanically perform the excavation shall be used. Augers shall be of sufficient diameter to convey the excavated material to the work pit."

Most DOT specifications require that steel casings be used during the AB process. Several DOT specifications, such as the one in North Carolina, state that it must be "demonstrated that the bored hole is never left unsupported." Some specifications

TABLE 5

INFLUENCE OF GROUND CONDITIONS ON AUGER BORING OPERATION *(7)*

	Wet Runny Sand	Wet Stable Sand	Dry Sand	Dry Clay	Wet Clay	Fine Gravel	Hard Pan	Coarse Gravel	Small Boulders (Cobbles)	Soft Solid Rock	Hard Solid Rock	Land/ Railroad Fill
Auger Speed	Slow	Fast	Slow	Fast	Med.	Med.	Slow	Slow	Slow	Slow	USE DRILL STEM METHOD	Cautious
Rate of Penetration	Fast	Fast	Fast	Fast	Fast	Fast	Med.	Low	Low	Low		Low
Cutting Head	Dirt	Dirt	Dirt	Dirt	Dirt	Rock	Rock	Rock	Rock	Rock		Rock
Wing Cutters	No	No	No	Yes	Opt.	Yes	Yes	Yes	Yes	Yes		Yes
Head Position	Inside	Inside	Inside	Flush	Flush	Outside	Outside	Outside	Outside	Outside		Outside
Bentonite	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No		Yes
Water Inside	No	No	No	Yes	Yes	Yes	Yes	No	No	No		Yes
Band	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
Bore Continuous	Yes	Yes	Yes	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.		Opt.
Clean Casing	Pack	Pack	Pack	Clean	Clean	Clean	Clean	Clean	Clean	Clean		Clean
Pit Base	Conc.	Stone	Opt.	Opt.	Stone	Opt.	Opt.	Opt.	Stone	Opt.		Conc.
Backstop	Conc.	Conc.	Conc.	Steel	Steel	Steel	Steel	Steel	Steel	Conc.		Conc.

Med.–Medium, Conc.–Concrete, Opt.–Optional limit the distance the cutting head can extend in front of the casing and the amount of over-cut.

Some DOTs indicated that the details of the crossing are determined by the utility responsible for the crossing. Others indicated that as long as the project is bonded, they felt that was sufficient. However, this is not consistent with a DOT's responsibility for ensuring roadway safety, traffic-carrying ability, and physical integrity (*1*). Therefore, it is essential that DOTs regulate crossing design details. For example, bore holes under fully or limited access-controlled highways should be required to have tracking and steering capability, adequate casing lubrication, and a casing leading-edge band (*3*). Figure 12 illustrates the banding used on the end of steel casings, which strengthens the leading edge of the casing.

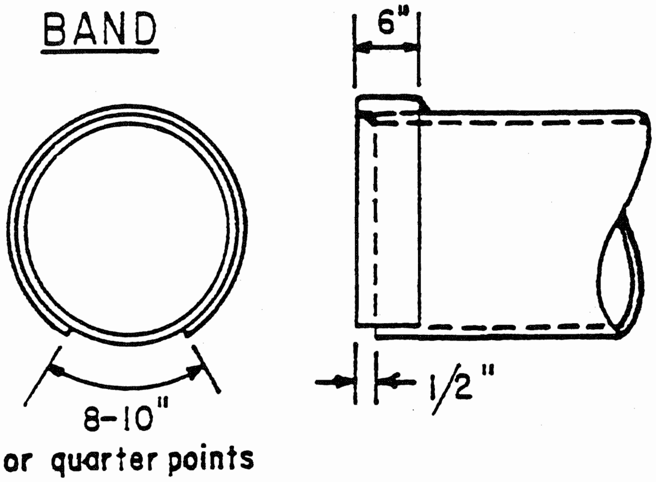


FIGURE 12 Casing leading edge "band detail" for auger boring method.

Emerging Technologies

A combination of new and old technology, which allows AB to be guided in both line and grade over long distances, is being used. A sonde transmitter is mounted on top of the casing pipe, just behind the cutting head. A locator (sonde receiver) used at the surface, in addition to the water level system for detecting grade, has proven to be effective for tracking the end of the casing during the boring operation. A horizontal and vertical articulating steering head was introduced in 1995, but is seldom used. Research is being conducted at Indiana University and Purdue University, Indianapolis, to develop a laser and inertia system compatible with AB, which will facilitate precise installation on line and grade.

A nonweldable steel casing pipe joint, a patented tongue and groove type, is available (Figure 13).

Case Study

Most municipalities and project owners require that contractors adhere to a strict line and grade. As reported by Nichol (*38*), a line and grade (LAG) steering system incorporating an articulated auger head at the leading edge of the pipe (Figure 14) is currently undergoing field testing to determine its capabilities. Figure 15 is an example of a finished LAG steering system assembly for AB. The precise location of the pipe is determined using a laser sensing system inside a 60-mm (2.5-in.) pipe mounted on top of the steel casing to be installed. Once the pipe is located, adjustments are made to the articulating head from the jacking pit using a screw mechanism.

FIGURE 13 Nonweldable steel casing pipe joint.

In one application, a 110-m (360-ft) crossing was made at Dallas–Fort Worth International Airport. The project entailed the installation of 600-mm (24-in.) steel pipe underneath one of the airport's busiest taxiways. The exit point of the completed bore was 6 mm (0.25 in.) high and 175 mm (7 in.) to the left of the design bore. The project was completed in a week.

In another application, a 73-m (240-ft) bore was made in Prince George's County, Maryland, near Camp Springs, for the Washington Suburban Sanitary Commission. A 910-mm (24-in.) steel casing in 6-m (20-ft) segments was installed beneath state Route 5, a four-lane divided highway. Line and grade were extremely critical because of the gravity sewer line's tie in to existing sewer lines on both ends. The bore was completed and the casing was installed in six 12-hr days, with a crew of six. Average production was 12 m (40 ft) per day. Four adjustments were made to the line and grade. The finished bore was 13 mm (0.5 in.) lower and 76 mm (3 in.) to the right of the planned bore.

Increasing sophistication in locating and steering technology (e.g., tracking the auger head with a sonde instead of water level and using a four-way (up/down and right/left) articulating head instead of a two-way (up/down) head) has led to

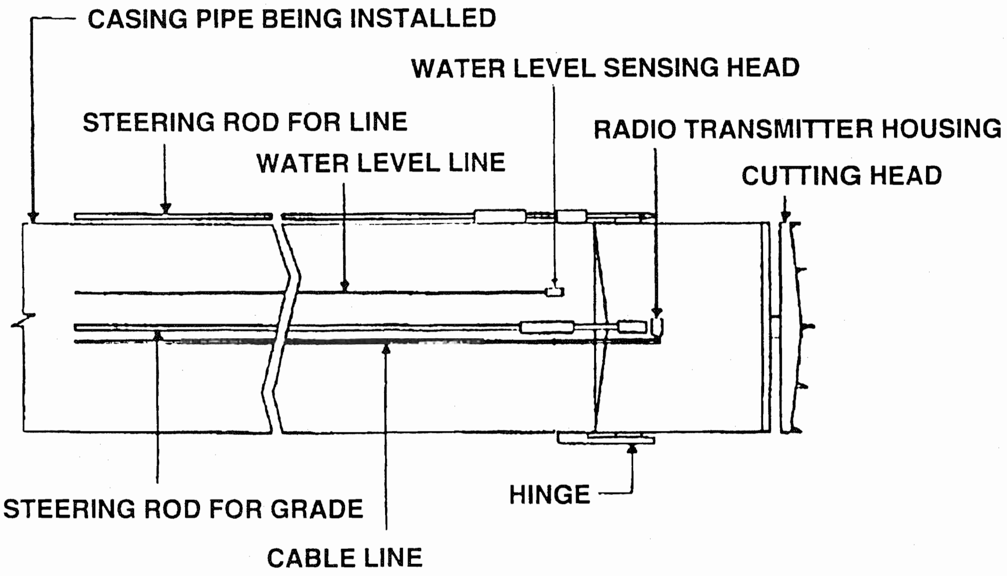


FIGURE 14 Line diagram of line grade (LAG) steering system for auger boring method. This drawing details the arrangement of the LAG system components. The view is from above, looking down on the steeing head and head casing.

FIGURE 15 Finished LAG steering system for auger boring method.

increased accuracy. Consequently, AB can provide an economical alternative to microtunneling for relatively short drives in stable ground conditions.

SLURRY BORING

SB involves the use of a drilling fluid to aid in the drilling and spoil removal process. This method, which has been in use for more than 50 years, is also referred to as "wet boring" or "fluid-assisted mechanical drilling." Typically, SB is associated with nontracking and nonsteering operations; however, sonde transmitters and locators can be used. The SB method is associated with the use of lower fluid operating pressures and higher flows than the mini-horizontal directional drilling (mini-HDD) method, which is discussed in Chapter 5.

SB sometimes is referred to as water jetting (WJ), which differs from SB in the basic principle of operation. WJ uses water pressure and flow to create a jetting action, which washes out a hole through the ground. It is very difficult to maintain control over a WJ operation; therefore, ground subsidence caused by excessive soil removal can result. Because SB mechanically cuts the bore hole, more control is inherent in the process. In addition, SB does not rely completely on eroding the soil with water.

Description

SB can be surface or pit launched; however, most systems are operated from a drive shaft. The drilling fluid is introduced into the drill tubing through a water swivel tee. This swivel allows the drill tubing to rotate while the fluid flows through the drill stem and exits through the drill bit. The drilling fluid used varies from water to a bentonite slurry to polymers. A drill bit compatible with soil conditions is attached to the drill tubing. As the drill tubing is rotated and pushed forward, the drill bit mechanically cuts the bore hole.

SB is a two-stage process that requires (1) the installation of a pilot hole and (2) development of the pilot hole into a bore hole that will accept the casing pipe. Following are the basic steps in the SB process:

1. Construct drive and reception shafts
2. Drill a pilot hole
3. Check accuracy of the pilot hole

4. Ream pilot hole to desired bore-hole diameter
5. Insert casing in the bore hole
6. Grout between the casing and bore hole.
7. Insert the desired carrier pipe
8. Construct the casing/carrier pipe bulkheads
9. Backfill and restore shaft areas.

Main Features and Application Range

Type of Casing

Because the SB process depends on the pipe casing or carrier pipe installation process, any type of pipe or cable can be installed. Pipe can be installed by tension forces, compressive forces, or both.

Diameter Range

The diameter of the pilot hole in SB varies from 50 mm (2 in.) to 125 mm (5 in.). The pilot hole is reamed to the size required for casing pipe insertion. Typically, SB is most suited to short, small-diameter applications in stable ground conditions, because in most cases the method involves an uncased bore hole. Therefore, this method is used for casings 50 mm (2 in.) to 300 mm (12 in.) in diameter, although casings 1,200-mm (48-in.) in diameter have been installed with SB in locations with compatible soil conditions.

Length of Bore

Typically, SB is a nondirectionally controlled process; therefore, the risk of obtaining an unacceptable pilot hole increases greatly with bore hole distance. Although the common bore hole spans are approximately 15 m (50 ft), bore holes longer than 100 m (328 ft) have been installed by means of SB.

Ground Movement

When proper installation procedures are adhered to in stable ground conditions, only minor ground subsidence should occur. Subsidence occurs when excessive soil is removed or when the bore hole collapses. Because soil is removed in the form of a slurry, it is often difficult for the operator to control excavation volume. Because the procedure requires that the bore hole be uncased for a period of time, the possibility exists for the bore hole to collapse before the casing pipe is installed. If the annular space between the casing pipe and bore hole is not filled with grout, the bore hole can collapse around the casing, thereby causing ground subsidence.

Required Working Space

The most critical working area in SB is the area for the drive shaft. The drive shaft needs to be located where it is accessible. The size of the drive shaft is determined by the diameter of the casing and the length of the drill tubing segments. A typical drive shaft is 1 to 2 m (3.3 to 6.7 ft) wide by 4.5 to 6.1 m (15 to 20 ft) long. A reasonable total working area, which includes lay-down space for drill tubing, casing pipe, carrier pipe, lifting equipment, pumps, and drilling fluid tanks, is 5 to 10 m (16.5 to 33 ft) by 15 to 20 m (50 to 66 ft).

Operator Skill

Operation of SB equipment is fairly simple. It requires an "aim and drill" approach. However, an experienced operator will know how to handle the unexpected and be aware of the limits of the system and when to terminate the process and switch to another method. The operator must be able to select the drill bits, reamers, and drilling methods that are suitable for the soil conditions encountered.

Accuracy

Accuracy with SB depends to a great extent on the operator's skill in setting up the boring operation. In stable homogeneous soils, a tolerance of 150 mm (6 in.) can be obtained for bore lengths of 9 to 18 m (30 to 60 ft). Because the drill tubing is flexible, the operator must allow for anticipated drop during the boring operation. Typically, the drop will be 25 to 50 mm (1 to 2 in.) per 3.3-m (10-ft) drill tube segment. Required tolerances usually are obtained through trial and error. If a pilot hole alignment is not within line and grade tolerance, the hole is abandoned. Because the diameter of the pilot holes is small, abandoned pilot holes usually are left open.

Recommended Ground Conditions

The ideal ground condition for SB is a firm, stable cohesive material with excellent stand-up characteristics. Wet noncohesive materials can be accommodated with SB, provided that special precautions are exercised. For example, berms can be constructed to prevent the drilling fluid from draining from the bore hole, which can help maintain a positive counterbalance pressure on the walls of the bore hole to keep them from collapsing.

Cost

The cost for SB is low for several reasons: (1) the method is relatively simple, (2) SB can be set up quickly and accomplished with a two- to three-person crew, and (3) SB equipment is inexpensive. The cost varies depending on the following:

- Diameter and length of the bore hole
- Soil conditions
- Casing installation and carrier pipe requirements
- Requirements for grouting the annular voids between the casing and the carrier pipe and the casing and the bore hole.

Typical SB costs are presented in Table 10 in Chapter 9.

Productivity Issues and Special Concerns

SB typically is used for small-diameter, short bore lengths. For example, a common size conduit is 100 mm (4 in.), with a bore length of 15 m (50 ft). A two- to three-person crew can be expected to accomplish three or four of these drives in a workday.

The major concern with using any type of fluid under a roadway is the potential for overexcavation. Consequently, the use of traditional SB is decreasing as mini-HDD becomes more widely accepted.

SB typically is used to install conduits less than 300 mm (12 in.) at depths less than 2 m (6 ft). Therefore, the time it takes for shaft construction may vary from several hours to several days depending on excavation embankment support requirements, depth, and soil conditions.

Transportation Agency Practices

As a result of problems arising from misuse, only a few state DOTs permit the use of traditional SB. Under the right conditions, however, SB can be effective. This method is used extensively in Texas, Louisiana, Mississippi, and Oklahoma. However, most state DOT specifications do not permit the use of water jetting, and SB is considered a form of water jetting.

Emerging Technologies

The only emerging technology associated with SB is the incorporation of tracking and steering capabilities. However, this method is being replaced rapidly by mini- and midi-HDD.

CHAPTER FOUR

PIPE JACKING AND MICROTUNNELING

Pipe jacking (PJ) and microtunneling (MT) are similar trenchless technology (TT) methods. Both rely on a horizontal jacking force to propel a shield or tunnel boring machine (TBM) along with the pipe string through the ground. PJ is a personnel entry technique, whereas MT does not require people to be inside the pipe as it is being jacked. PJ has been used for more than 100 years. MT was developed in 1975 and introduced in the United States in 1984.

PIPE JACKING (PJ)

The term "pipe jacking" can be used to describe a TT method process. When used to describe a process, the term can apply to several methods. For example, with auger boring (AB), the casing pipe is jacked through the ground as the spoil is transported through the casing by the augers. Thus, this process is a form of PJ. However, when PJ is referred to as a method, it has distinct characteristics. In this synthesis, PJ is used to describe a method. Detailed information on PJ can be found in the literature (*3–5,7,8,10,11,20–24,35,39,40*).

PJ is a TT method for installing a prefabricated pipe through the ground from a drive shaft to a reception shaft. The pipe is propelled by jacks located in the drive shaft. The jacking force is transmitted through the pipe to the face of the PJ excavation. The excavation is accomplished, and the spoil is transported out of the jacking pipe and shaft manually or mechanically. Both the excavation and spoil removal processes require workers to be inside the pipe during the jacking operation. Therefore, the minimum recommended diameter for pipe installed by PJ is 1075 mm (42 in.). Although smaller diameter pipes have been jacked successfully, it is difficult and can be hazardous for workers to function inside them. Rescue efforts can be more difficult in a small diameter pipe; therefore, it is critical that adequate ventilation be provided and that Occupational Safety and Health Administration (OSHA) confined-space requirements are complied with.

Description

Figure 16 illustrates the typical components of a PJ operation. The cyclic procedure uses the thrust power of the hydraulic jacks to force the pipe forward through the ground as the PJ face is excavated. The spoil is transported through the inside of the pipe to the drive shaft, where it is removed and

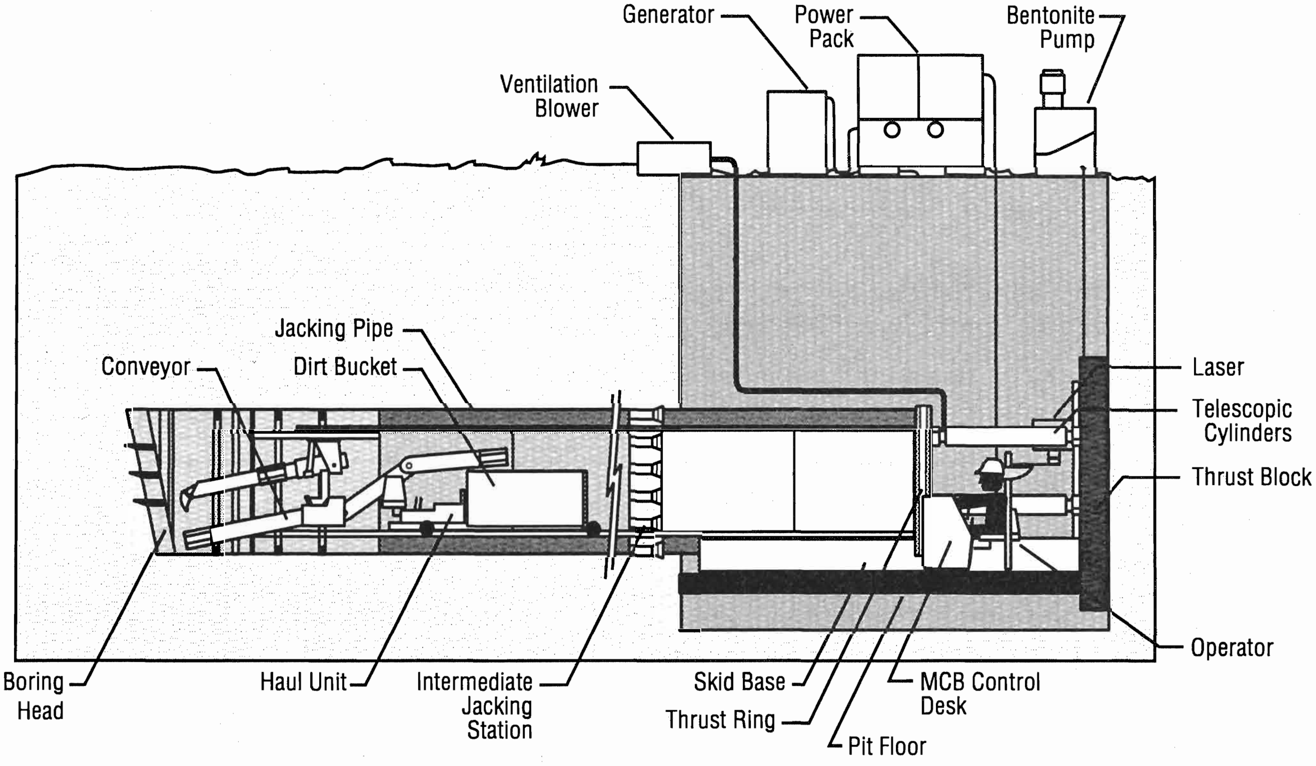


FIGURE 16 Typical components of a pipe jacking operation.

disposed of. After each pipe segment has been installed, the rams of the jacks are retracted so that another pipe segment can be placed in position for the jacking cycle to begin again.

Figure 17 illustrates a variety of excavation techniques that are available. Excavation is accomplished by hand mining or mechanical excavation within a shield or by a TBM. The excavation method selection is based on a careful assessment of the subsurface for instability (*39*). If there is any possibility of excavation face collapse, soil stabilization techniques must be considered. Common soil stabilization techniques are dewatering and grouting. Alternatively, closed face earth-pressure balance or slurry microtunneling methods may be appropriate.

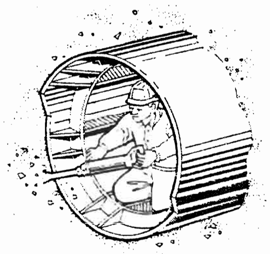
Because of the large jacking forces required to push large diameter pipe through the ground, the design and construction of the jacking shaft are critical to the success of the project. The shaft floor and thrust reaction structure must be designed to withstand the weight of heavy pipe segments being placed on them repeatedly.

There are five main approaches for removal of the excavated soil from the excavation face to the drive shaft for further disposal (*35*). These soil conveyance systems include (1) wheeled carts or skips, (2) belt or chain conveyors, (3) slurry systems, (4) auger systems, and (5) vacuum extraction systems.

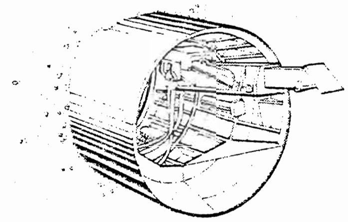
The basic PJ procedure follows:

1. Place jacking equipment in the drive shaft.
2. Place PJ track in shaft and adjust to the proposed design line and grade.
3. Install laser guidance system.
4. Place shield or TBM on the jacking tracks.
5. Mate jacking push plate to shield or TBM.
6. Advance shield or TBM through the prepared opening in the forward shaft support structure. Begin the excavation and spoil removal process.
7. Continue excavation, spoil removal, and forward advancement until shield or TBM is installed.
8. Retract jacks and push plate.
9. Place first pipe segment on the jacking tracks.
10. Mate push plate to pipe and pipe to the shield or TBM.
11. Initiate forward advancement, excavation, and spoil removal.
12. Repeat pipe jacking cycles until complete line is installed.
13. Remove shield or TBM from reception shaft.
14. Remove jacking equipment and tracks from drive shaft.
15. Restore site as required.

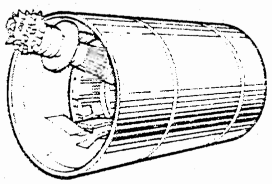
Important optional equipment available for the PJ method include a pipe lubrication system and intermediate jacking stations (IJSs). The pipe lubrication system consists of mixing and pumping equipment necessary for applying a bentonite or polymer slurry to the external surface of the pipe. An adequate lubrication system can decrease jacking forces by 20–50 percent; however, the most common reduction factor range would probably be 20–30 percent (*22*). IJSs are used for pipes, 1.2 m (36 in.) in diameter or larger, between the drive shaft jacking plate and the jacking shield or TBM to redistribute the total required jacking force on the pipe.



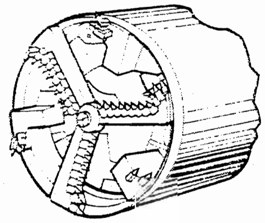
Hand Shield: An open face shield for manual excavation



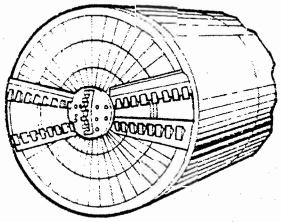
Backacter: An open face shield with a mechanical backacter



Cutter Boom: An open face shield with a cutter boom or road header



Tunnel Boring Machine (TBM): A shield with a rotating cutting head



Earth Pressure Balance Machine (EPBM): A full face tunnel boring machine with a balanced screw auger to control the face pressure

FIGURE 17 Variety of excavation techniques available in pipe jacking operation.

IJSs consist of a steel cylinder installed between two pipe segments in the pipeline being jacked. Hydraulic jacks are then placed around the internal periphery of the steel cylinder. The IJS is pushed forward through the ground with the pipeline until its operation is necessary. When the main jacks reach approximately 80 percent of the design load, the jacking force on the pipe behind the IJS is held constant, and the jacks in the IJS are activated to propel the forward section of the pipeline (*23*).

Main Feature and Application Range

Type of Casing

The type of pipe used for the PJ method must be capable of transmitting the required jacking forces from the thrust plate in the jacking shaft to the jacking shield or TBM. Steel pipe, reinforced concrete pipe (RCP) (*41*), and glass-fiber reinforced plastic pipe (GFRP) are the most common types of pipe used in PJ. Polymer concrete pipe (PCP) is commonly used in Europe for PJ and microtunneling. PCP is now available in the United States (*22,42*).

The quality of the pipe can be a significant factor in the success of a project. Items that should be considered when specifying a jacking pipe are strength, squareness, straightness, roundness, and smoothness. A cushioning material should be used between the pipe segments to assist with distributing the jacking loads evenly over the cross section of the pipe. The most common type of material used as a cushion material is plywood (*35,43,44*).

Diameter Range

The minimum recommended diameter for pipe installed by PJ is 1,075 mm (42 in.). Theoretically, there is no limit to the size of pipe that can be jacked; however, the largest usually is approximately 3.7 m (12 ft) in diameter, with the most commonly used sizes ranging from 1,220 mm (48 in.) to 1,830 mm (72 in.) in diameter.

Length of Bore

The length of PJ drive is determined by the amount of available jacking thrust and the compressive strength of the pipe. The jacking thrust can be minimized or managed by providing an adequate over cut, applying adequate lubrication between the outside surface of the pipe and the bore hole, maintaining accurate line and grade control, using high-quality pipe products, and using IJSs. The longest PJ project in the United States had a continuous jacking length from drive shaft to reception shaft of approximately 1,050 m (3,500 ft) (*45*). The most common PJ drive lengths range from 150 m (500 ft) to 305 m (1,000 ft).

Ground Movement

With proper selection and use of PJ equipment, ground movement (i.e., heave and subsidence) can be kept to a minimum. Typically, ground movement is maintained at less than 25 mm (1 in.). Care must be taken at all times to ensure that the excavation face is properly supported to prevent sudden collapse. Ground movement and monitoring are discussed in detail in the literature (*46–48*).

Required Working Space

The site must provide space for storage and handling of pipe and spoil and adequate space for the shaft. The size of the jacking shaft is determined by the pipe diameter, pipe segment length, jacking shield dimensions, jacking system dimensions, thrust wall design, pressure rings, and guide rail system. For example, the drive shaft size for a PJ project using pipe 1,525 mm (60 in.) in diameter with segments 3.3 m (10 ft) in length would require a 3.3- to 4.6-m (10- to 15 ft) by 5.2- to 10m (17- to 33-ft) vertical shaft, depending on selection of jacking and excavation equipment.

Operator Skill

Operating traditional PJ equipment does not require much training. However, PJ is as much an art as it is a science; therefor, it requires a skilled operator to detect early warning signs of problems developing and to know what corrective action to take. The more sophisticated TBMs used in PJ require a substantial amount of training.

Accuracy

Maintaining line and grade control is often important for the proper hydraulic operation of a utility system, and it is important to the success of the PJ operation. Every deflection in the line and grade increases the jacking forces. A reasonable anticipated tolerance is ± 75 mm (3 in.) for alignment and ± 50 mm (2 in.) for grade (*23*). Any adjustments to line and grade should be made gradually[i.e., 6 mm in 3 m (0.25 in. in 10 ft)].

Recommended Ground Conditions

Sandy clay is the most favorable soil condition for PJ. However, with the proper selection and use of available excavation heads, PJ can take place in many types of ground conditions. For example, PJ is possible in unstable soil conditions as long as special precautions are taken, such as using a closed-face machine and compressed air or slurry shield to counterbalance the ground pressure.

Cost

Costs for PJ projects are provided in Table 10 in Chapter 9.

Productivity Issues and Special Concerns

A reasonable productivity range for PJ projects is 10 m (33 ft) to 30 m (99 ft) per shift with a four- or five-person crew. Factors that can affect productivity include the presence of groundwater, unanticipated obstructions such as boulders or other utilities, and changed conditions such as encountering wet silty sand after selecting equipment for stable sandy clay. The primary concern for all PJ contractors is predicting subsurface behavior. Site investigation recommendations and soil condition information are reported on extensively in the literature (*22,23,47*).

Transportation Agency Practices

Survey responses indicated that if state DOTs had specifications covering any aspect of TT, it would be for PJ. This was expected because PJ has been in use for more than 100 years. The Texas DOT PJ specifications, which are fairly representative of other state DOT PJ specifications, include the following:

- Adequate shafts must be provided.
- A clearance of 50 mm (2 in.) may be provided at the top of the pipe.
- Excavation may not exceed 610 mm (24 in.) ahead of the shield.
- Plywood pipe joint cushioning material shall be 13 mm (0.5 in.) thick for pipe diameters 750 mm (30 in.) or less and 19 mm (0.75 in.) thick for pipe diameters greater than 750 mm (30 in.).

These elements address (1) shaft construction to ensure that shafts are designed to withstand the large jacking thrust; (2) the avoidance of overexcavation above or ahead of the pipe, which may lead to loss of support to the ground; and (3) uniform transfer of the jacking thrust to the pipe through a properly designed joint material. In the event of overexcavation or the development of voids, external grouting of the pipe usually is required.

Emerging Technologies

There have been a number of technical breakthroughs in PJ equipment and operation in recent years that greatly enhance the capacity and quality of PJ, especially for smaller pipeline applications.

To provide an alternative to jacking clay pipes for sanitary sewer applications, two new composite pipe systems with high corrosion and abrasion resistance were introduced to the U.S. market in 1996. The first one, Pipeform, is a high-strength concrete pipe protected by an external and internal layer of polyvinyl chloride (PVC). It is manufactured in the United States. The second one is a PCP from Germany (*50*). PCP has been used in Europe for nearly 2 decades. In addition to its inherent corrosion-resistant properties, this polymer concrete pipe features extreme high compressive strength and optimal hydraulic design. Both piping systems are expected to have a great potential.

Although the techniques involved in the microtunneling and PJ processes are well understood by the industry, the mechanism of the ground-machine-pipe interaction has not been thoroughly explained by existing geotechnical and mathematical models. Since 1986, a series of field studies on PJ and microtunneling projects has been carefully monitored by a research group from Oxford University, with sections of heavily instrumented jacking pipe. Factors such as joint misalignment and jacking force transfer, ground movement, and pipe-soil friction have been addressed. Data from the latest field monitoring are still under evaluation. The findings indicate that the mechanism of the ground-machine-pipe interaction can be best represented using a soil-structure interaction model (*51*). Other research efforts are under way to develop a more comprehensive and consistent approach to predict the variation of jacking force (*52*).

Case Studies

Tanwani (*53*) reported on the installation of two sets of twin box culverts under railroad tracks in the southwest part of Fort Worth, Texas, as part of the West Vickery Boulevard Drainage Relief System. These concrete box culverts were jacked in place under the railroad without disruption of service. The soil encountered was a mixed-face condition with clayey silt at the bottom, overlaid by railroad fill. The soil cover was very shallow, and care was essential to avoid overexcavation. PJ was selected from several alternatives considered because of its ability to handle mixed-face soil conditions while allowing good control over line and grade.

For the installation of the boxes, a boring machine was used to install two steel casings 400 mm (16 in.) in diameter on line and grade. These casings were filled with concrete and served as guide rails for the box to slide on. A nonmagnetic tracking and guidance system was used to avoid interference from the casings. After installation of the casings, an 8.8-m by 6-m (29-ft by 20-ft) jacking pit was prepared with a concrete floor and a concrete backstop capable of withstanding 4,500 kN (1 million lb) of thrust. The box sections were 3 m by 2.7 m (10 ft by 9 ft), with a 250-mm (10-in.) wall thickness, and weighed 142 kN (32,000 lb). Although a smaller jacking pit would have sufficed, it was more economical to modify the pit used for installation of the casings.

A steel shield 19 mm (0.75 in.) thick was used on the leading box to prevent overexcavation and to ensure the safety of the personnel inside. The shield extended 600 mm (2 ft) in front of the leading edge of the box and was reinforced to prevent buckling. Bentonite ports were installed directly behind the shield to ensure that the voids were filled and to reduce friction.

A solid-steel frame conforming to the dimensions of the box was constructed to serve as a push ring. Another frame was constructed to uniformly transfer the jacking force to the push ring. The boxes were jacked in place using a 1.5-m (60-in.) boring machine. The steel casings under the boxes ensured vertical alignment while a laser beam was used to check horizontal alignment. Soil was excavated at the face using a loader and a backhoe. A portable platform enabled the movement of the equipment in and out of the boxes.

The average production rate was 3.7 m (12 ft) per 12-hr shift, and maximum thrust encountered was 2,590 kN (580,000 lb). Work was stopped and the boxes were allowed to stand during the first weekend. The jacking force increased greatly. As a result, the decision was made to work around the clock to prevent "freeze-up." Total construction time for installing 32 m (105 ft) of twin concrete box culverts was 2 months.

This case study illustrates that PJ, a proven technique for installing large-diameter underground utilities in North America, can be successfully used even under difficult ground conditions.

The most difficult conditions in underground construction are not any particular geological conditions. Instead they are unexpected conditions.

Tarkoy (*54*), reported on a case in which four soil bores were taken, one each at the shafts and two in between the shafts. The soil boring profile of anticipated conditions indicated silt. Boulders were encountered only in one instance at a shallow depth (1.5 m or 4.5 ft). A percussion drill was used to determine the top-of-rock; however, "refusal" was never thoroughly investigated despite the fact that a previous drilling log indicated a conflicting rock line. Shortly after the PJ operation commenced, large boulders were encountered. The situation was complicated by the fact that overlying the boulders was a layer of unstable flowing silt that could not be dewatered from the surface. The upper face had to be breasted from within the excavation before attempting to remove the boulders to avoid losing the face. The contractor decided to consolidate the face by grouting on one shift and mining the boulders on the next shift. Progress was substantially slower than anticipated.

Unanticipated rock in a trenchless project can be disastrous in an open-faced operation such as PJ. Removal of rock in small-diameter excavations may require blasting, which may disrupt and destabilize otherwise stable ground.

Two unfortunate practices are still prevalent in site exploration: (1) using drillers without professional supervision or proper logging and (2) ending borings at refusal rather than drilling through the obstructions to determine the nature of the obstruction.

Unanticipated ground conditions can jeopardize a trenchless project. The presence of unanticipated rock or unstable ground conditions requires corrective measures that cause cost overruns and delays. This case study emphasizes the importance of thorough and professional subsurface investigation.

MICROTUNNELING

No universally accepted definition for microtunneling (MT) exists. However, MT can be described as a remotely controlled, guided PJ process that provides continuous support to the excavation face (*22*). MT was developed in 1975 in Japan and introduced in the United States in 1984. As of September 1996, more than 164,600 m (540,000 ft) of pipe ranging in diameter from 250 mm (10 in.) to 3,500 mm (136 in.) had been installed in the United States by MT on 215 projects by 50 contractors (*55*). MT use has certainly grown in the United States; however, many claim that the growth has not been rapid and has been significantly less than expected. Most MT work has occurred in Texas, and the number of MT machines in the United States is less than 50. Figure 18 demonstrates the growth of the MT industry in North America during the past 10 years.

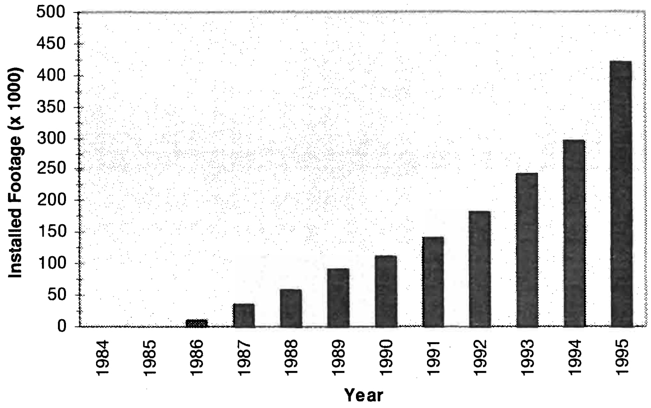


FIGURE 18 Growth of microtunneling in North America (*55*).

Description

MT is a trenchless construction method for installing conduits beneath roadways in a wide range of soil conditions, while maintaining close tolerances to line and grade from the drive shaft to the reception shaft. Initially, the MT definition restricted projects to nonpersonnel-entry size, but the size varied. For example, this size was 900 mm (36 in.) in diameter in Japan and 1,000 mm (40 in.) in Europe. In the United States, because the same type of system can be used to install pipe 250 mm (10 in.) in diameter as well as pipe larger than 3 m (10 ft) in diameter, less emphasis is placed on size. As of September 1995, almost 37 percent of all pipe installed in the United States and Canada by the use of MT was more than 900 mm (36 in.) in diameter.

The MT process is a cyclic PJ process. The steps listed in the discussion on the PJ method presented earlier in this chapter apply equally to MT.

The most common way to categorize MT is by the spoil removal system (i.e., slurry or auger) (*7,8*). These systems have differing capabilities for controlling ground conditions by earth pressure balance at the face. A slurry MT system is more capable of handling wet, unstable ground conditions. Both auger and slurry MT systems have five independent systems:

- Microtunnel boring machine (MTBM);
- Jacking or propulsion system;
- Spoil removal system;

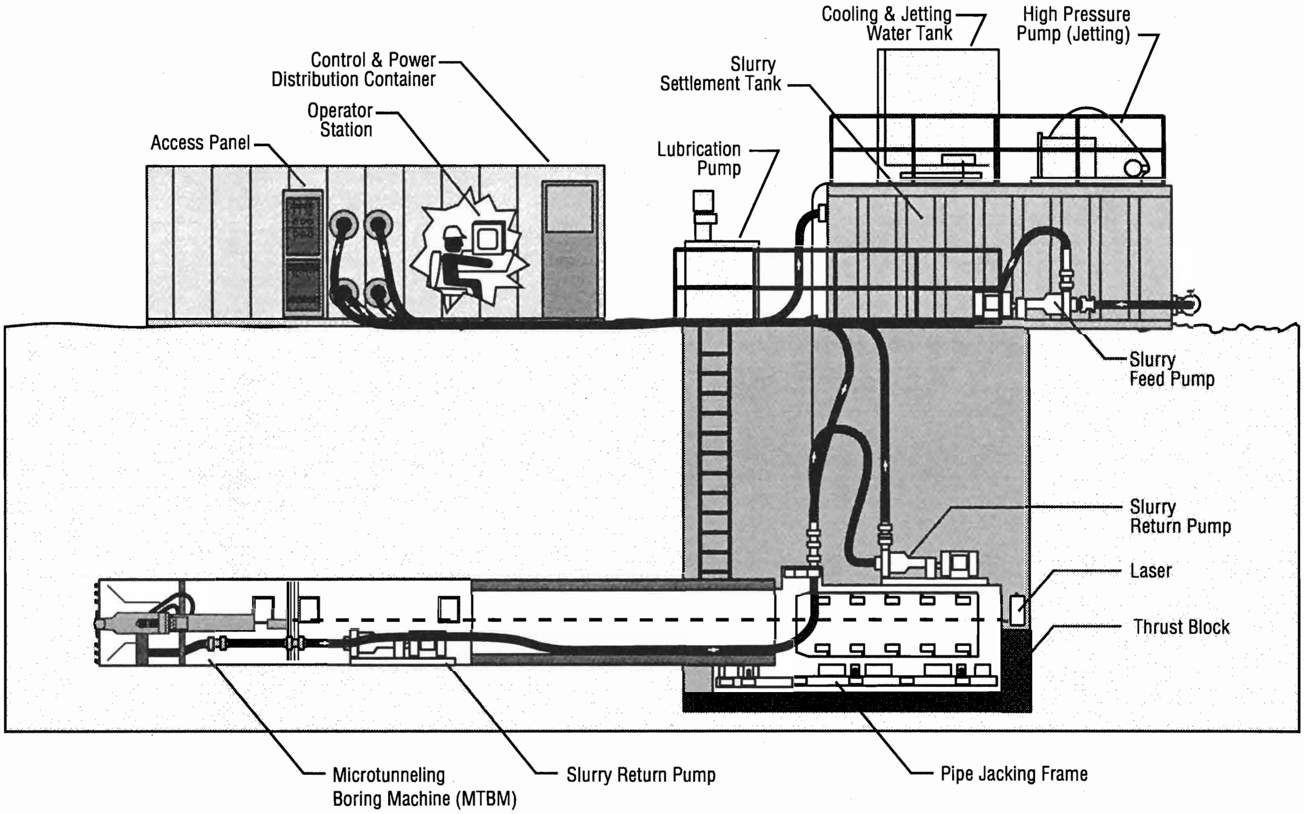


FIGURE 19 Basic components of a microtunneling system.

- Laser guidance and remote control system; and
- Pipe lubrication system.

Figure 19 illustrates the basic components and position of these systems. The significance and capabilities of these systems are well described in the literature (*8,10,11,22–24,35,43,44*).

The previous discussion on PJ relating to the (1) significance of drive shaft design and construction, (2) methods to minimize jacking forces, and (3) use of intermediate jacking stations (IJSs) applies equally to MT. IJSs can be used with pipe diameters of 762 mm (30 in.); however, they become much easier to use with pipe diameters of 1,070 mm (42 in.) and larger. Retrieval of jacks in the IJSs requires personnel entry.

Main Features and Application Range

Type of Casing

The most common types of pipe used with MT are steel, reinforced concrete, vitrified clay, and glass-fiber reinforced plastic. A small amount of ductile iron pipe and PVC pipe have been installed with MT.

Diameter Range

Based on U.S. experience, the range in diameter for MT is from 250 mm (10 in.) to 3,500 mm (136 in.). The most common range is from 610 mm (24 in.) to 1,220 mm (48 in.).

Length of Bore

The longest MT drive from the drive shaft to the reception shaft installed in the United States is 475 m (1,560 ft). This project was located on Staten Island, New York (*51*). The most common range for drive lengths is from 150 m (500 ft) to 303 m (1,000 ft) for slurry MT systems and from 61 m (200 ft) to 122 m (400 ft) for auger MT systems.

Ground Movement

With proper selection and use of MT equipment, ground movement (i.e., heave and subsidence) can be minimized and typically maintained at less than 25 mm (1 in.). Ground movement and monitoring programs are discussed in detail in the literature (*46–48*).

Required Working Space

Adequate working space needs to be provided at the drive shaft to accommodate the required equipment and materials for the MT operation. The space requirement is determined by the drive shaft size, which can range from 5 m by 10 m (16 ft by 33 ft) to 15 m by 30 m (50 ft by 100 ft), depending on pipe diameter and length and equipment dimensions. Adequate working space typically would range from 6 m (20 ft) to 12 m (40 ft) wide and from 23 m (75 ft) to 46 m (150 ft) long.

Operator Skill

The operating systems are relatively sophisticated and require a high degree of skill to operate properly. The operator must be trained to interpret data obtained from various gauges and decide what action needs to be taken. Unlike PJ, all work is done blind. The operator cannot see the excavation face.

Accuracy

In most cases, a tolerance of ± 25 mm (1 in.) on line and grade is attainable (*8,23*). For example, on the Staten Island project, 475 m (1,560 ft) of pipe 1,525 mm (60 in.) in diameter was installed by MT with a maximum deviation from line and grade of 25 mm (1 in.) (*51*).

Recommended Ground Conditions

The most favorable ground conditions for slurry MT is wet sand, and the most favorable ground conditions for auger MT is a stable sandy clay. However, a wide selection of MTBM cutter heads are available that provide the capability to handle a range of soil conditions, including boulders and solid rock. Typically, boulders of 20 to 30 percent of the machine diameter can be removed by MT by crushing the boulders into particle sizes of 19 mm (0.75 in.) to 25 mm (1 in.) and smaller.

MT experience in solid rock is limited. Nevertheless, some manufacturers claim that their equipment can handle rock up to a uniaxial unconfined compressive strength of 207,000 mPa (30,000 psi) (*55*). However, one contractor was unable to complete a project using a rock MT machine on a solid face, hard, abrasive rock in Atlanta after the cutter disk face failed as a result of abrasion three times in the first 4.5 m (15 ft), using up 5 weeks of the construction schedule. The contractor used drill and blast techniques to finish the project.

Cost

The cost of MT is determined by numerous factors. Table 10 in Chapter 9 lists typical MT costs in the Midwest.

Productivity Issues and Special Concerns

A special concern that is critical to the success of an MT project is the ability to predict and control jacking forces. These forces affect four basic elements of the MT process (*52*):

- Required pipe strength;
- Required capacity of the jacking system;
- Design of the jacking thrust block structure; and
- Length of pipe to be jacked in a single drive.

The components of jacking forces, prediction of jacking forces, and examples of jacking force performance on numerous projects are described elsewhere (*52*). These examples illustrate what can be done to control the jacking force.

An MT crew of four to eight can obtain a production rate of 9 m (30 ft) to 18 m (60 ft) per shift; however, production rates exceeding 61 m (200 ft) per shift have been achieved (*22*).

Transportation Agency Practices

Only three of the 33 states and six Canadian provinces that returned the questionnaire indicated that they had MT specifications. Many of the 215 MT projects completed in the United States involved installing conduits beneath roadways. Most state DOTs only get involved in MT as the permit issuing authority. Many DOTs stated that they left the details of the crossing up to the utility and issued permits if the utility posted the necessary bond to cover the liability.

Emerging Technologies

Microtunneling capabilities continue to expand. Improved PJ materials are available. Developments in the laser guidance and steering system that permit a high degree of automation have proven effective in increasing the jacking distance capability. In a so-called "laying pipe with low bearing force" (LLB) microtunneling system, the incorporation of a continuous steel casing inside the jacking pipes allows the jacking force to be transferred directly to the MTBM shield through the steel casing instead of through the pipe string (*56*). With this approach, pipes of low-bearing-strength materials (e.g., PVC) can be installed by single-pass jacking methods over a long distance.

With a multireferenced laser or self-guided steering system, longer drives and those with curves can be accomplished by microtunneling methods with satisfactory accuracy in both line and grade.

Another technology under development relates to computer-aided automatic control of complicated microtunneling operations. Fuzzy logic theories have been incorporated into the control system to simulate manual control operation by an experienced operator.

A new microtunneling system with a retrievable MTBM shield, which enables the front shield to be withdrawn from the starting pit after the drive is completed or unexpected obstructions are encountered, has been developed. This feature will greatly enhance the safety aspect of microtunneling projects under freeways or railroads where open-cut retrieval is prohibited or operationally infeasible.

Rock drilling mechanisms have been extensively studied at the Colorado School of Mines (*57*). As a result, an efficient rock boring cutter head equipped with single disk cutters has been developed. Today, a more versatile cutter head design that is capable of handling a wide range of soil variations is still under research and development. Other ongoing research includes developing more accurate survey systems for curved microtunnel drives.

Case Study

LaFaso (*58*) reported that Iseki Poly-tech, Kawasaki Steel, and NKK jointly developed a sophisticated, rapid, and precise method for installing gas transmission lines using a specially developed microtunneling machine called the "Trunk Mole."

Conventional trenchless methods of installing gas mains usually involve jacking a concrete pipe as a casing and installing gas mains inside the casing. This is essentially a two-phase operation. Greater efficiency is achieved by using a single-pass approach, as is the case with the Trunk Mole system. This method involves the use of double steel pipes. The outer thrust pipe is designed to slide over the inner gas main pipe, allowing for simultaneous jacking and installation. By applying all the thrust force to the outer pipe, no load whatsoever is applied to the gas main. The design of the thrust pipe allows it to withstand high jacking loads. Use of steel allows the contractors to go longer distances, without the need for intermediate jacking stations.

A further advantage arises from the fact that the outer casing is only slightly larger than the gas main, which is not the case with traditional methods using a thick concrete pipe.

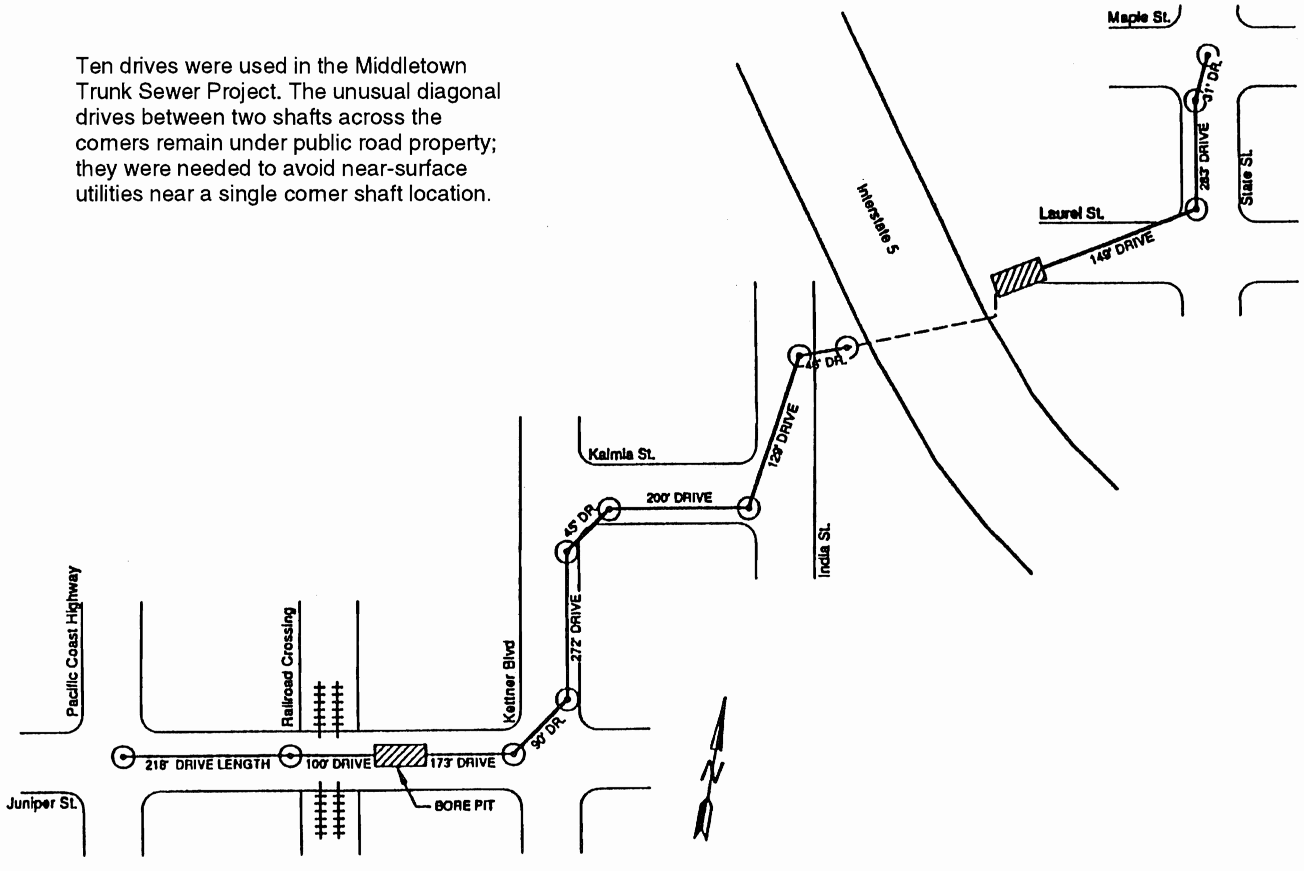
Since 1994, Tokyo Gas has successfully installed more than 2,000 m (6,500 ft) of pipes under streets and roadways in some of Japan's largest cities. The company has experienced 15 percent reduction in costs and typically a 20 percent reduction in time required to complete an installation.

One of the biggest disadvantages of MT is the cost. This case study illustrates that new technological advances in MT attempt to address the cost issue by making the process faster and cheaper.

Case Study

As reported by Jeypalan (*59*), the old Middletown Trunk Sewer (MTTS), which was constructed in the 1920s, collects and conveys wastewater from a large drainage basin north of downtown San Diego. The MTTS varies in diameter from 300 to 525 mm (12 to 21 in.). Sewage backups prompted a study to determine the flows and examine the condition of this 75-year-old sewer. The study determined that the actual flows in the sewer were much greater than its design capacity. It was recommended that the section of the sewer line 350 mm (14 in.) in diameter be replaced with a pipeline 450 mm (18 in.) in diameter.

It was anticipated that open trench construction of the sewer would be highly disruptive because it would involve digging trenches 11.5 m (38 ft) deep through some of the busiest streets in the city. The lowest bid for open cutting was $981,168. The MT option was bid at $1,135,182, the second lowest bid overall. MT was chosen to reduce surface disruption and prevent loss of revenue to local business. When construction began in February 1993, MTTS became the first MT



Ten drives were used in the Middletown Trunk Sewer Project. The unusual diagonal drives between two shafts across the corners remain under public road property; they were needed to avoid near-surface utilities near a single corner shaft location.

FIGURE 20 Middletown trunk sewer project in San Diego *(59)*.

project in the city of San Diego and only the second on the West Coast involving the use of a clay jacking pipe.

The subsurface soil consisted essentially of manmade fill. The natural material consisted of mostly silty sand with some clay and gravel deposits. Groundwater was encountered at an average depth of 4.5 m (15 ft).

A small (i.e., 660 mm (26 in.) outside diameter) shield MT machine with a pressurized slurry removal system for excavated material was used. High groundwater pressure is balanced by coordinating the slurry pressure, flow, and density. To advance the mole, the cutter head is rotated at a constant rate while being pushed by two hydraulic jacks located in the jacking pit. The rate at which the jacks advance is constantly monitored and adjusted to prevent the soil in front of the cutter head from heaving or settling.

Direct jacking clay pipe was chosen from the various alternatives available (clay, steel, concrete, fiberglass reinforced, and so on) for its high chemical resistance. The inside diameter of the pipe was 500 mm (19.7 in.). The average jacking force used was 130 to 180 kN (15 to 20 tons). The largest jacking force, 490 kN (55 tons), was used for the 66-m (218-ft) drive (Figure 20) through silty sand above the groundwater table. The lowest jacking force, 9 kN (1 ton), used for the 14-m (46-ft) drive through clayey material below the water table.

Approximately 460 m (1,510 ft) of clay pipe was installed between 12 utility holes. The pipe was used in 1.2-m (4-ft) sections. The construction crew consisted of seven people: one to operate the mole from the control cabin, two to connect the pipe segments in the pit, two to lower the pipe into the pit using a crane, and one to ferry pipe sections to the pit using a tractor loader. The jacking and receiving pits were excavated to just below what was to become the invert elevation for the new utility holes. The line and grade requirements for this project were 80 mm per 100 m (1 in. per 100 ft). One of the problems during construction was encountered when the mole ran into a concrete block, which was believed to be the remnant of the shoring system used to install the MTTS 75 years ago. This happened in the middle of India Street 10 m (32 ft) below ground. The mole was recovered by open trench excavation, resulting in a change order and an additional cost of $50,000. At the west end of the project (Figure 20), petroleum-contaminated soil was encountered. This had been indicated in a prior geotechnical report. The contaminated soil was hauled away to a Class III landfill at a cost of $15,910, and the contaminated groundwater was discharged into the public sewer system at a cost of $9,500.

The MTTS project was completed in 113 workdays. The average rate of installation was 13.7 m (45 ft) per day at $2,700 per m ($825 per ft).

Although the MT alternative was bid higher, the decision to use MT over open-cut trenching was justified by the "social cost savings." Open-cut trenching could have resulted in more costly change orders as a result of the increased volume of contaminated soil and groundwater to dispose of and treat. Also, for open cutting, work conditions would have been hazardous because of congested urban streets.

CHAPTER FIVE

HORIZONTAL DIRECTIONAL DRILLING

Horizontal directional drilling (HDD) was pioneered in the United States in the early 1970s by an innovative road boring contractor who successfully completed a 183-m (600-ft) river crossing using a modified rod pushing tool with no steering capability. By integrating existing technology from the oil well drilling industry and modern surveying and steering techniques, today's directional drilling methods have become the preferred approach for installing utility lines, ranging from large-size pipeline river crossings to small-diameter cable conduits.

The HDD industry is divided into three major sectors—large-diameter HDD (maxi-HDD), medium-diameter HDD (midi-HDD), and small-diameter HDD (mini-HDD, also called guided boring)—according to their typical application areas. Although there is no significant difference in the operation mechanisms among these systems, the different application ranges often require corresponding modification to the system configuration and capacities, mode of spoil removal, and directional control methods to achieve optimal cost-efficiency. Table 6 compares typical maxi, midi, and mini-HDD systems.

Description

Directional drilling methods utilize steerable soil drilling systems to install both small- and large-diameter lines. In most cases, HDD is a two-stage process (Figures 21 and 22). Stage 1 involves drilling a pilot hole approximately 25 to 125 mm (1 to 5 in.) in diameter along the proposed design centerline. In Stage 2 the pilot hole is enlarged to the desired diameter to accommodate the pipeline. The pilot hole is drilled with a surface-launched rig with an inclined carriage (Figure 1), typically adjusted at an angle of 5 to 30 deg with the ground. Most systems adopt either fluid-assisted drilling or a high-pressure fluid jetting method to create or enlarge the bore hole. In a few instances, some mini-HDD systems utilize dry bore systems (with compressed air) in hard, dry soils and calcified or soft rock formations.

Fluid-Assisted Mechanical Drilling

Soil cutting in the mechanical drilling process is performed by rotating the drill bit, assisted by the thrust force transferred from the drill string. The mechanical drill bits may vary from a slim cutting head with a slanted face for small and short bore applications to a diamond-mounted roller cutter used with mud motors for large and long crossings. For small systems used for mini-HDD, directional steering control is accomplished mainly by the bias caused by the slanted cutter head face. For large systems used for maxi-HDD, a bent housing (a slightly bent section between 0.5 and 1.5 deg of the drill rod) is used to deflect the cutter head axis from the following drill string. In both small and large systems, a curved path can be followed by pushing the drill head without rotating, and a straight path can be drilled by applying simultaneous thrust and torque to the drill head.

High-Pressure Fluid Jetting

In a typical fluid jetting process, a soil cavity is formed by injecting a small amount of high-pressure (7 to 28 Ma (1,000 to 4,000 psi)), high-velocity fluid from small jetting nozzles. For short bores with stable soil conditions, the jetting fluid can be water; however, in most cases, bentonite or polymer-based slurry is used to stabilize the bore hole and prevent its collapse. Because the energy of high-pressure flow dissipates

TABLE 6

COMPARISON OF MAIN FEATURES OF TYPICAL MAXI-, MIDI- AND MINI-HORIZONTAL DIRECTIONAL DRILLING HDD SYSTEMS

System Description	Product Pipe Diameter	Depth Range	Bore Length	Torque	Thrust/Pullback	Machine Weight (including truck)	Typical Application
Maxi-HDD	600–1,200 mm (24–48 in)	≤ 61 m (200 ft)	≤ 1500 m (5,000 ft)	≤ 108.5 kN-m (80,000 ft-lb)	≤ 445 kN (100,000 lb)	≤ 267 kN (30 ton)	River, Highway crossings
Midi-HDD	250–600 mm (10–24 in)	≤ 23 m (75 ft)	≤ 274 m (900 ft)	1–9.5 kN-m (900-7,000 ft-lb)	89–445 kN (20,000–100,000 lb)	≤ 160 kN (18 ton)	Under rivers and roadways
Mini-HDD	(50–250 mm) (2–10 in)	≤ 4.5 m (15 ft)	≤ 183 m (600 ft)	≤ 1.3 kN-m (950 ft-lb)	≤ 89 kN (20,000 lb)	≤ 80 kN (9 ton)	Telecom and Power cables, Gas lines

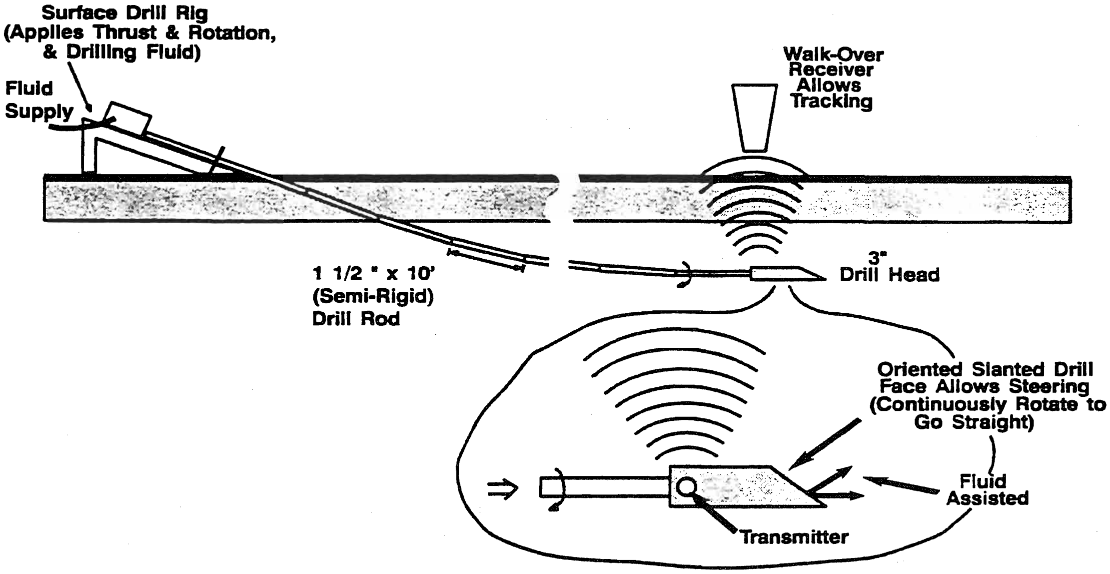


FIGURE 21 Pilot hole boring process in mini-horizontal directional drilling method *(57)*.

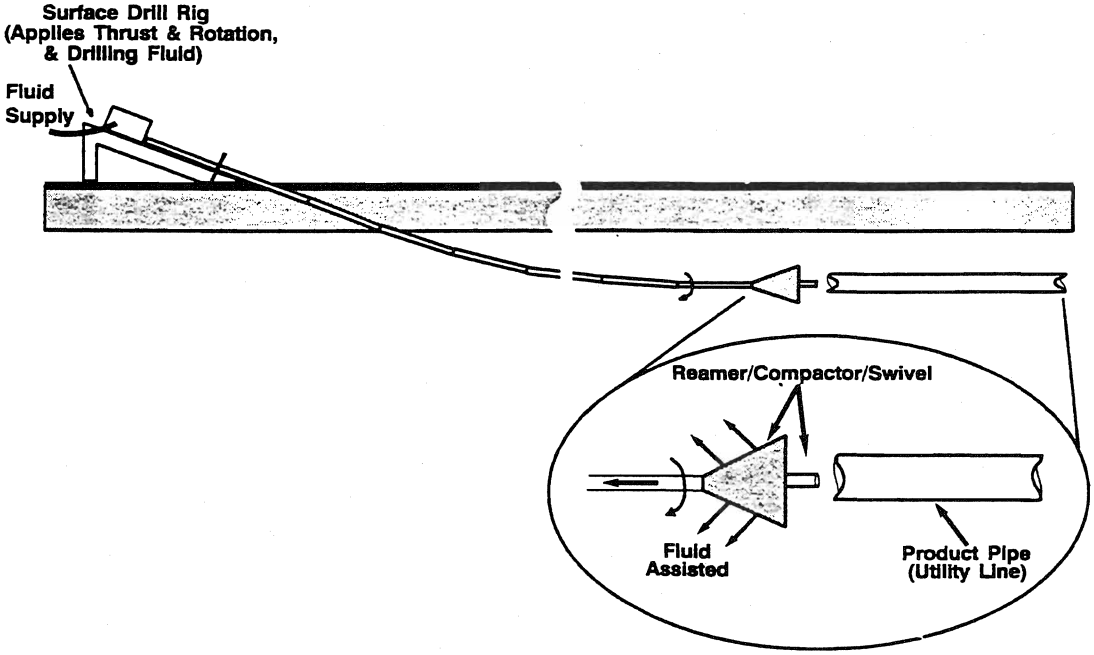


FIGURE 22 Backreaming/pullback process in mini-horizontal directional drilling method *(57)*.

quickly after the fluid exits the nozzles, soil overcutting is unlikely and the risk of cutting through adjoining utilities is virtually eliminated. However, for maxi- and midi-HDD systems in which the fluid circulation method is used, there is still the potential that soil will be eroded by the drilling fluid.

In mini-HDD, drill bits usually are rotated by the torque transferred from the drill string. For larger systems, the required drilling torque can be derived from a down-hole mud motor located just behind the drill bit. A medium-pressure, low-volume (3.5 to 7 L/min (1 to 2 GPM)), drilling fluid is used to assist in the mechanical drilling process. There are two variants of drilling fluid use: fluid recirculation and fluid suspension. Fluid recirculation involves (1) moving the soil cutting from the bore hole in the form of slurry with a large volume of drilling fluid, (2) cleaning the hole, and (3) refilling the hole with the slurry. The fluid suspension method, which uses only a small amount of fluid, keeps the soil cuttings in the slurry, with few or none removed from the hole. Theoretically, the choice between these two approaches depends on soil conditions; however, in practice, the fluid recirculation method usually is used in maxi-HDD systems and the fluid suspension method is used extensively in mini-HDD systems.

Midi-HDD systems employ a combination of recirculation and suspension methods. For long crossings requiring the use of a down-hole mud motor, high flow rates and large amounts of drilling fluid are necessary for providing the soil cutting torque. Such large volumes of fluid can act as the conveyance medium for spoil removal. Recirculation reduces the extra stress in the drill string caused by suspended soil cuttings, which might be very high for a long drive. For small, short bores at a shallow depth, a down-hole mud motor is not used and the spoil removal usually is not required because the soil cuttings can be kept in the fluid suspension.

A unique technique for maxi-HDD involves the use of a washover pipe or casing with a large internal diameter, to be slid over the drill string during the pilot bore drilling process. When in place, the washover pipe can significantly reduce the friction around the drill string and provide stiffness to the drilling system. It also can be used to perform the prereaming and final reaming and pullback operation.

Directional steering capacity is achieved by incorporating offset jets and direction sensing and steering devices into the system. The deflection force created by the offset and angled fluid jets is used to form a curved drill path. An alternative to the offset jets is a special steerable head that will bend slightly under increased fluid pressure. Rotation of the jetting head can be accomplished by using a hydraulically or electrically driven down-hole motor, rotating a string of steel drilling rods, or attaching a special auger-type fin device behind the jetting head.

The progress of the pilot hole is monitored by a specially designed surveying system, either a walkover system or an electromagnetic down-hole navigational system. In a walkover system, the drill head is equipped with a sonde (also called a beacon) transmitter behind the drill bit (Figure 23). The sonde is powered by battery and emits signals continuously. These signals can be picked up on the ground with a hand-held receiver (Figure 1). The receiver provides data on the position, temperature, depth, and orientation of the drill bit. An alternative detection system, the electromagnetic down-hole navigational system can be used in conjunction with a series of four electrical cables positioned directly above the desired path and secured in place. The cables, which can be laid directly on top of the street or highway, do not interfere with traffic flow. The cables transmit an electromagnetic signal that is picked up by the navigational instruments in the drill head. These instruments determine the position of the drill head relative to the center of the cables and relay this information continuously to a computer on the operator's console. In case of deviations from the desired path, the operator can make necessary adjustments.

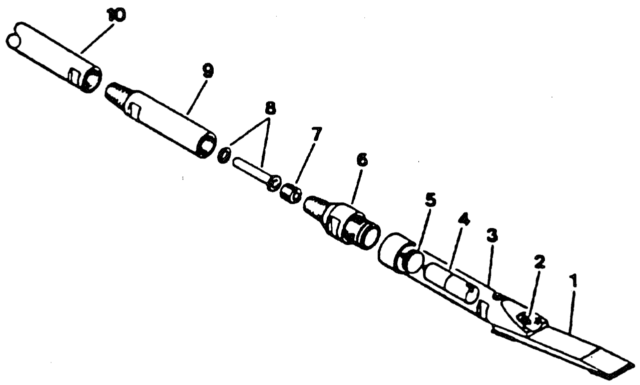


FIGURE 23 Horizontal directional drilling head assembly (60): 1) bit, 2) fluid nozzle, 3) beacon housing, 4) beacon, 5) beacon housing plug, 6) end cap, 7) screen sub plug, 8) screen, 9) screen sub, and 10) drill pipe.

After the drill head (or pilot string and washover pipe) exits at the desired location, reaming devices are attached for the pullback operation. This stage involves enlarging the pilot hole to the desired diameter to accommodate the pipeline. The utility is attached to the reamer (Figure 22) with a swivel to ensure that the rotation (torque) applied to the reamer is not transmitted to the utility. The reamer enlarges the bore hole to the required size, and the utility is installed. For large diameters (greater than 500 mm (20 in.)), an intermediate prereaming may be required before pulling the utility into place. Prior to the pullback operation, the pipeline is usually assembled to its full length and tested.

Main Features and Application Range

Type of Casing

In general, the pipe to be installed is limited to one that can be joined together continuously, while maintaining sufficient strength to resist the high tensile stresses imposed during the pullback operation. In maxi- and midi-HDD, steel pipe is the most common type of casing used. However, butt-fused, high-density polyethylene pipe (HDPE) also can be used. HDPE pipe, small-diameter steel pipe, copper service lines, and flexible cables are some of the common types of pipe materials being used today in mini-HDD.

Diameter Range

In maxi- and midi-HDD, the size of pipe installed can range from 75 mm (3 in.) to 1,200 mm (48 in.) in diameter. Multiple lines can be installed in a single pull, but only in the case of small-diameter pipes. The installation procedure for multiple lines is the same as for single lines, with the bundle being pulled back as a single unit along the prereamed profile. A significant multiple line crossing is more than 600 m (2,000 ft) in bore length and consists of five separate lines, pulled as one, ranging in size from 150 mm (6 in.) to 400 mm (16 in.). The maximum size pipe that can be installed by the mini-HDD system is 300 mm (12 in.) in diameter.

Length of Bore

The length of bore in HDD is determined by the type of soil and site conditions. Bore spans can range from 120 m (400 ft) to 1,800 m (6,000 ft) for maxi- and midi-HDD. However, small lengths are not economically feasible because of the high operational costs of these systems. Mini-HDD is capable of installing pipelines and utilities 180 m (600 ft) in one continuous pass to a specified tolerance.

Ground Movement

In mini-HDD, the typical pipe size is less than 100 mm (4 in.). For small pipeline installations, the soil cuttings are not removed. Instead, they remain in suspension in the drilling fluid, resulting in compaction of the soil around the bore hole as installation takes place. The drilling fluid usually is under pressure, which helps stabilize soils such as sand and soft clay.

Surface subsidence ordinarily is not a concern with mini-HDD because there is minimal overcutting of the soil. On the other hand, with maxi- and midi-HDD, ground disturbances must be taken into consideration during both the design and construction phases of a directionally drilled crossing. Care must be taken because significant forces are created by the flow rates and pressures at which the bentonite slurry is circulated through the drill string to operate the down-hole motor and wash the cuttings from the bore hole. The typical flow ranges from 280 to 380 L/min (75 to 100 GPM); the typical pressure is 69 kPa (10 psi).

The pressure and high flow rates may cause the slurry to flow into a soil strata, causing heaving of the soil. The pressure and high flow rates also may cause the soil to erode, thus leaving behind a void that may subsequently collapse and cause a surface settlement. These problems can be eliminated by ensuring that adequate depth is maintained and that compatible soil conditions exist and by closely monitoring the flow rates and pressure of the drilling fluid.

Required Working Space

The directional drilling process is a surface-launched method; therefore, it usually does not require access pits or exit pits. If utility installation is being undertaken, pits may be required to make connections with the existing utility. The rig working area should be reasonably level, firm, and suitable for movement of the rig. For maxi- and midi-HDD, an area of 120 m (400 ft) by 60 m (200 ft) is considered adequate. The equipment used in mini-HDD is portable, self-contained, and designed to work in congested areas.

Operator Skill

The directional drilling method is fairly sophisticated and hence requires highly skilled operators. Operators must have knowledge of soil conditions and geological formations, drill head compatibility with site conditions, down-hole drilling, the operation of sensing and recording instruments, and the interpretation of computer printout data. Training is essential for these operators.

Accuracy

Installation accuracy depends on the surveying system being used. For maxi- and midi-HDD, an accuracy of within 1 percent of the bore length is considered acceptable. In mini-HDD, the drill head usually can be located within 150 mm (6 in.). Steering accuracy is within 300 mm (12 in.). It has been reported that the steering accuracy of mini-HDD systems can be within 75 mm (3 in.) when walkover sonde detectors are used. However, in actual field operation, such accuracy seldom is achieved because of the high drilling speeds preferred by contractors and limitations due to operators' skill levels and the steering system. Sometimes, the bore may deviate from its intended path by as far as 0.5 m (2 ft). This might not be a problem in open fields; however, it can cause severe problems under urban roadways with congested subsurfaces.

Recommended Ground Conditions

Clay is considered ideal for HDD methods. Cohesionless fine sand and silt generally behave in a fluid manner and stay suspended in the drill fluid for a sufficient amount of time; therefore, they are also suitable for HDD.

High-pressure fluid drilling systems (mini-HDD and midi-HDD) normally do not damage on-line existing utilities and thus are safe for subsurface-congested urban areas. Fluid cutting systems, which are most suitable in soft soil conditions, have been used widely in sand and clay formations. Although small gravel and soft rock formations can be accommodated by higher fluid pressure and more powerful jets, steering accuracy might suffer.

Generally, mechanical drilling systems (mini-HDD) can be applied in a wider range of soil conditions than fluid jetting methods. A pilot hole can be drilled through soil particles ranging from sand or clay to gravel, and even in continuous rock formations, by using suitable drill heads; however, problems might occur in spoil removal, pilot hole stabilization, and backreaming operations. Today's technology enables large drilling operations to be conducted in soil formations consisting of up to 50 percent gravel.

Cost

Typical costs for directional boring methods are shown in Table 10 in Chapter 9.

Productivity Issues and Special Concerns

HDD systems have the highest pilot hole boring rate of advancement among all trenchless new installation methods. For mini-HDD rigs, a three-person crew is sufficient. In suitable ground conditions, a pipeline as long as 180 m (600 ft) can be installed in 1 day by a regular work crew.

TABLE 7

POTENTIAL PROBLEMS AND POSSIBLE SOLUTIONS FOR HDD PROCESS

Problem	Probable Cause	Solution
Lost position of drill head	Locator showing inaccurate readings	Check locator performance. Try push and pullback of the drill head to track it.
Difficulties in product pipe pullback	Product pipe pushed into the sidewalls of the curved bore hole	Alternatively push and pull to free pipe
Drill head exits off target	Steering difficulties and/or inaccurate locator	Pull back head reasonable distance and redrill
Back reaming difficulties	Possible blockage due to cobbles or gravel	Push reamer back out. Detach pipe and reamer. Pullback with drill bit to clear obstruction
Steering difficulties	Hit bedrock or a hard layer at steep angle	Drill very slowly to pass through hard ground
Fluid migrates to surface	Fissured rock or hydraulic fracture	Lower the fluid pressure
Alignment too tight for product pipe	Difficult steering section	Enlarge the section of the bore hole
Loss of bore hole stability	Fluid pressure fluctuation between rig and drill face	Increase applied fluid pressure to just below maximum permissible value
Groundwater seepage washes out drilling fluid	High groundwater pressure or low drilling fluid rate	Adjust drilling fluid weight and flow rate
Plugged fluid jets	Debris in drill string	Remove and clean
Separation of drill string immediately behind reamer	Damaged swivel assembly	Blind push backwards and dig up
High drill torque requirements	Worn bit/cutting head	Replace
Increased torque overnight	Collapsed hole/cohesive soil	Drill continuously or rotate periodically overnight
High pullback forces	Radius too small	Flatten drilling path curves
Warning siren and/or flashing lights	Advance Electric Strike system activated because drill head is too close to or struck a live electric underground line	Do not move. Stay on the protected mat. Always wear safety shoes and gloves.

The disposal of slurry mixed soil cuttings needs to be considered in advance, especially if the fluid circulation method is to be used. Although bentonite is not considered a toxic material by the Environmental Protection Agency, the acceptability of such spoil material varies among local regulations as well as landfill owners. Thorough site investigation is extremely important because corrective measures applied midway in the drilling or backreaming operation can be very time-consuming and costly.

When boring under roadways and other environmentally sensitive areas, the use of pressured fluid may cause serious concerns about the possible deleterious effect of bentonite caused by lateral and vertical slurry migration. Care also should be taken to prevent ground movement and loss of slurry at installations with shallow soil cover.

As is true with any type of construction, some problems may be encountered during horizontal drilling project execution. Table 7 summarizes potential problems, their possible causes, and actions required to remedy the problems.

Transportation Agency Practices

Only a few highway agencies have developed standards or specifications for HDD. Caltrans and the DOTs in Michigan, Minnesota, Oregon, New York State, and Indiana have HDD standards. The following is an example of a typical specification. It was developed by the Department of Water and Power in the city of Los Angeles, California, in 1993:

1) The system shall utilize a mixture of bentonite clay and water emitted through small diameter jets at a maximum pressure of 27.5 Ma (4,000 psi) to work through soil, stabilize the bore hole, and lubricate the conduit being installed.
2) The system shall be capable of hitting a 300 mm (12 in.) target at distance up to 120 m (400 ft) away in one continuous tunnel.
3) The boring tool shall turn on a radius as small as 11 m (35 ft) and be detectable to a depth of 9 m (30 ft), and
4) Voids or air pockets in the soil shall be minimal with no surface subsidence.

Specifications also need to address other important considerations such as (1) the nature and extent of subsurface exploration; (2) procedures for approving alternate drilling fluids such as polymers; (3) minimum depth of cover; (4) qualifications of contractors and crews; (5) contingency planning in the event of roadway surface disturbance, including subsidence or upheaval, a drill bit breaking the surface, and drill fluid escaping to the surface; and (6) backfilling requirements for abandoned, off-target pilot holes.

Emerging Technologies

Development of directional drilling techniques focuses on both large and small drilling systems. For large drilling systems, more powerful rigs are being developed to facilitate continuous installation of up to 6,300 m (25,000 ft) in length. Compact drilling rigs are available for use in confined spaces, which frequently are encountered in congested urban areas. Also, the midi-HDD system has emerged to fill the gap between maxi-HDD and mini-HDD. Mini-HDD can be used to install relatively large diameter pipelines at short river crossings on highways.

Future developments will focus on computer-aided automatic steering control and extending the application of HDD to more challenging soil conditions. With such systems, a detailed, as-constructed record can be obtained for future use.

A recent innovation in drilling fluid is the use of polymer gels to replace bentonite slurries. Typically, 3.8 L (1 gal) of gel is required for 3,000 L (800 gal) of water. This eliminates the need for a large tow truck to mix bentonite slurry.

The Gas Research Institute (GRI) is in the final stage of developing guidelines and computer-aided design tools for the installation of polyethylene gas pipe using directional horizontal drilling (*54*). The interactive software developed will facilitate design and planning tasks and help improve engineering and final project quality. In addition, it will accelerate the acceptance of the directional drilling techniques among design engineers.

Research is under way to extend the application of HDD to gravity sewers, which require high line and grade accuracy believed to be out of reach with conventional directional drilling tools. A new generation of guided boring equipment featuring improved tracking, boring, and installation technology is under development. A trial project to install a gravity sewer line with a gradient of 1.5 percent and distances between utility holes of 100 m (330 ft) is being considered.

An area being investigated that has the potential of revolutionizing the directional drilling industry is "obstacle detection." Current directional systems are not capable of detecting obstacles such as boulders, cobbles, pipelines, and cables. Future developments could include the capability of detecting the types and locations of obstacles, thus permitting the operator to choose a route that avoids obstructions or maneuvers around them. Such a capability would help eliminate accidents.

Case Studies

As reported by Iseley (*55*), DOT engineers from Mississippi, Missouri, and Arkansas were invited to a field demonstration to prove to regulators that voids are not caused by the high pressure/low volume systems that fall under the category of fluid-assisted mini-HDD. A DirectLine DL810 fluid-assisted directional boring system was used. A water jet whose pressure was 21 Ma (3,000 psi) was used to make the pilot hole. The soil was very stiff clay with 125- to 250-mm (5- to 10-in.) boulders.

After the pilot bore was completed, a 50-mm (2-in.) polynucleic acid (PNA) plastic pipe was placed on the reamer and pulled back the entire length of the bore. The ground was dug up by a backhoe and hand-excavated near the pipe to expose the utility. The results: no voids. Solid, damp soil was left around the utility at a thickness of less than 1 in. If left undisturbed, this portion of surrounding soil eventually will dry out, leaving the utility firmly installed in solid ground.

This case study illustrates that pressure jetting does not have to result in soil washout and subsequent undermining of the structure supported by the soil (roadway), provided the pressures and volumes are monitored closely to ensure that they are within a safe working range.

Melsheimer (*56*) reported on a neighborhood of Anaheim, California, where the high-voltage service was badly in need of replacement. In just 1 month, a residential area in the city had experienced more than 20 electrical outages. The city awarded a contract to replace existing buried cable with a 75-mm (3-in.) polyethylene duct by trenchless methods. Portions of the job required work in areas of extremely limited access. Walls, fences, and landscaped yards built up to the sidewalk made it impossible to use a surface-launched directional drilling rig. Instead a pit-launched rig, Quick Shot, Model 5120-5-SP10, manufactured by Melfred Borzall (Figure 24), was used.

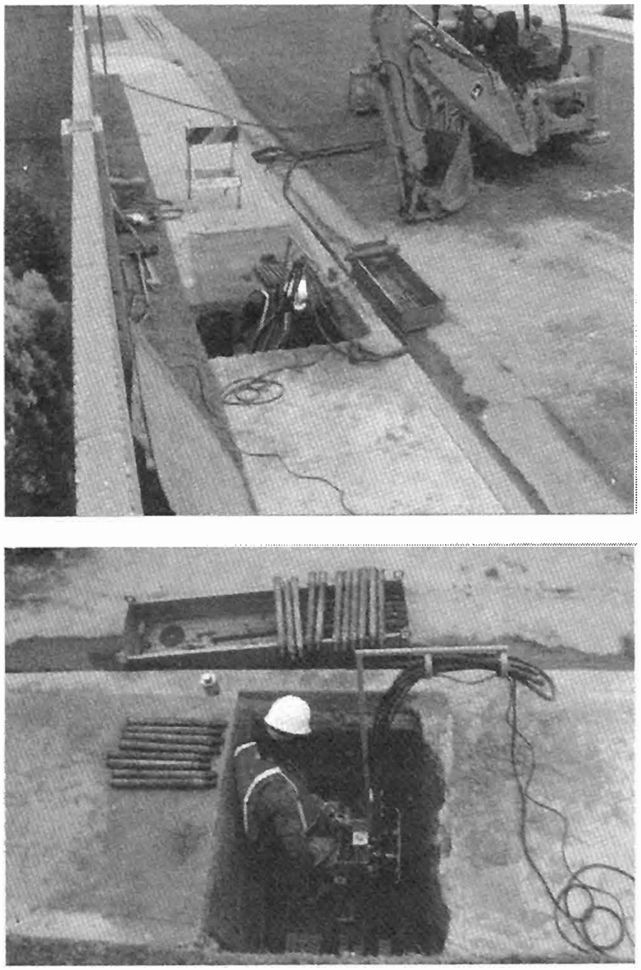


FIGURE 24 Pit launched mini-horizontal directional drilling (*63*): *(Top)* The block wall eliminated options for drilling without damage to curb or street. *(Bottom)* The quick shot requires a compact setup pit. With this model, only a 3-ft by 4-ft pit, half of a sidewalk flag, at this site.

The machine utilizes drill rods 1.5 m (5 ft) in length and 45 mm (13/4 in.); offers a 44.5-kN (10,000-lb) thrust/ pullback; and can operate from a pit 2,400 mm (95 in.) long by 750 mm (30 in.) wide.

The rig was used to drill a pilot hole and backream a hole 250 mm (10 in.) in diameter for the installation of a bundle of four 75-mm (3-in.) conduits. The average depth of the conduits was 1.5 m (5 ft) below ground. The 120-m (400-ft) installation was completed in a single workday.

This case study illustrates the advances taking place in the TT industry to reduce the size of equipment, make it portable, and make its application in highly congested urban areas easier.

CHAPTER SIX

PIPE RAMMING

Pipe ramming (PR) is a trenchless construction method for installing steel conduits through the ground beneath roadways from a drive shaft to a reception shaft. The method involves using the dynamic force and energy transmitted by a percussion hammer attached to the end of the pipe. PR is an extension of the impact (percussive) moling method, which will be discussed in Chapter 7. PR permits the installation of larger casings in a wide range of soil conditions. PR use, which has evolved in recent years, is expanding rapidly. Most DOT specifications do not address PR; however, when proposed, it has been accepted with few objections. The process is simple and similar to the pile driving process. It provides continuous casing support during the drive with no overexcavation, and it does not require that water be used for excavation.

Description

The two major categories of PR are closed-face and open-face. With the closed-face PR technique, a cone-shaped head is welded to the leading end of the first segment of pipe to be rammed. This head penetrates and compresses the surrounding soil as the casing is rammed forward. The soil-pipe installation interaction that results when this method is used is similar to the interaction that takes place when soil compaction methods, described in Chapter 7, are used.

With the open-face PR technique, which will be the focus of this chapter, the front of the leading end of the steel casing/conduit remains open so that a bore hole of the same size as the casing (i.e., a cookie-cutter effect) can be cut. This allows most of the in-line soil particles to remain in place, with only a small amount of soil compaction occurring during the ramming process. The open-face PR process is shown in Figure 25. Figure 26 illustrates a typical PR field setup. Figure 27 shows the spoil being ejected while the pipe is being rammed in place.

To facilitate the PR process, the leading edge of the first casing usually is reinforced by welding a steel band 305 to

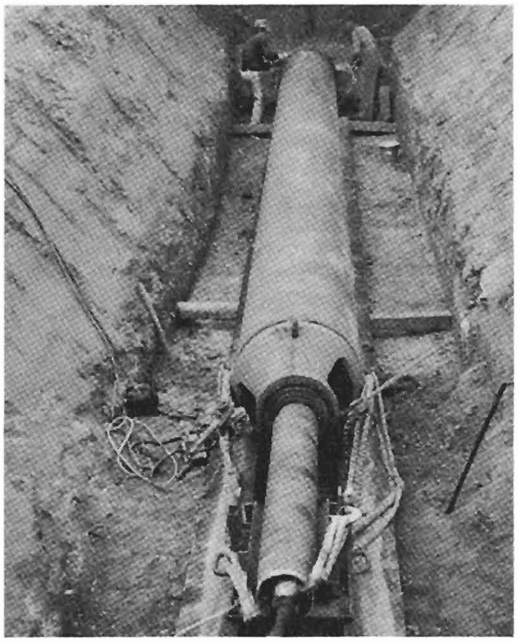


FIGURE 26 Typical field setup for pipe ramming method.

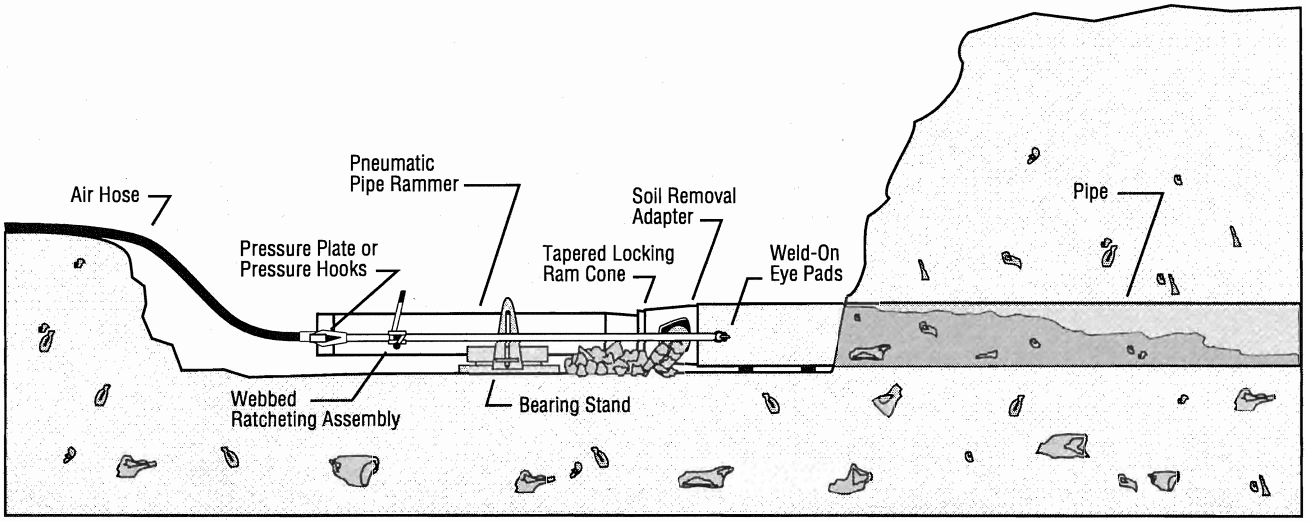


FIGURE 25 Pipe ramming process.

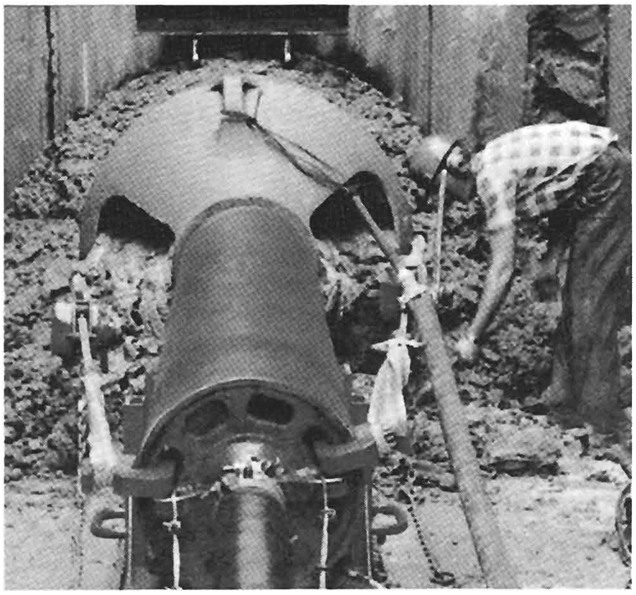


FIGURE 27 Ejection of spoil during pipe ramming method.

610 mm (12 to 24 in.) wide around the exterior surface of the pipe. After the casing installation process is complete, the soil that has entered the casing is removed by applying compressed air or water from either end for small-diameter casings. For large casings, augers can be used to mechanically remove the soil from the inside of the pipe.

A properly constructed drive shaft is a major component of a successful PR project. The casing pipe is unguided; therefore, the line and grade accuracy is determined by the initial setup as well as the ground conditions encountered. There is a tendency for the pipe to drift downward slightly as a result of gravitational forces during the PR process. Therefore, when possible, it is advantageous to initiate the drive from the upstream side of the crossing.

The PR procedure is as follows:

1. Construct an adequate shaft.
2. Install a cone or band on the leading edge of the casing.
3. Place casing in drive shaft and adjust for desired line and grade.
4. Attach hammer device and connect to pneumatic or hydraulic power source.
5. Initiate the drive and continue until installation is complete. (If multiple pipe segments are being used, after each segment is installed, remove the hammer, weld another pipe segment to the end of the previous casing, and repeat the cycle until the installation is complete.)
6. Remove cone, if used, or clean out casing as required.
7. Remove equipment.
8. Restore area as required.

Main Features and Application Range

Type of Casing

The type of casing and conduit is limited to steel pipe. The pipe must be able to endure the repeated impact loads of the percussive hammer. Therefore, the pipe's wall thickness is a very important design consideration.

Diameter Range

Typical diameters of pipe installed by PR are 100 to 1,524 mm (4 to 60 in.) for open-face PR and 100 to 200 mm (4 to 8 in.) for closed-face PR.

Length of Bore

The typical lengths of PR bores are 15 to 61 m (50 to 200 ft); however, installations involving bores greater than 91 m (300 ft) have been accomplished.

Ground Movement

The possibility of ground heaving and subsidence needs to be evaluated for the type of soils anticipated. For closed-face PR operations, it is recommended that the depth of cover be at least 10 times the diameter of the pipe being installed. Heaving usually is not a problem with open-face PR operations because there is minimum ground disturbance outside the pipe. Subsidence can occur with either technique in some soils because of consolidation resulting from the vibratory action of the hammer.

Required Working Space

Adequate site access and working space are essential for a successful installation. The working space should provide room for handling and storing steel casing pipe materials and PR and casing welding equipment. Drive shaft size is determined by the installation process. For example, a 30-m (100-ft) drive could be accomplished in a single drive as long as the casing pipe is welded together before the drive begins, or it could be accomplished in five drives with 6-m (20-ft) pipe segments. The required working space at the drive shaft typically is 6 to 12 m (20 to 40 ft) in width by 10 to 20 m (33-66 ft) in length.

Operator Skill

One of the most significant features of the PR process is simplicity. Therefore, the level of operator skill is minimal. Because PR is unguided, the main concern of the operator is to ensure proper initial setup and proper support of pipe segments as they are being moved forward in the drive shaft.

Accuracy

Accuracy depends on the initial setup, length of drive shaft, diameter, probability of encountering obstructions, and soil conditions. For projects requiring a high degree of precision, oversize casings usually are installed by PR so that the carrier pipe can be adjusted within the casing. PR accuracy ranges from 1 to 3 percent of the length; however, because the process is unguided, deviations from line and grade sometimes can be significant.

Recommended Ground Conditions

A significant feature of the PR technique is its versatility. It is suitable for a wide range of soil conditions, from stable to unstable, with or without the presence of high groundwater.

Cost

PR usually is cost-effective for suitable applications. Typical costs are presented in Table 10 of Chapter 9. The table does not include the costs for pipes, drive shafts, or reception shafts. The cost of the drive shaft varies greatly with the required length and depth. The cost of constructing drive shafts ranges from $3,000 to $10,000, but can be much greater if extensive excavation support is required. The reception shaft only needs to be adequate so that the drive cone, if used, can be retrieved and access is provided for soil removal.

Productivity Issues and Special Concerns

PR is relatively simple. Usually a 2- to 3-person crew is all that is needed for small applications. Under suitable soil conditions, the typical rate of penetration ranges from 50 to 250 mm/min (2 to 10 in./min). Line and grade control is a primary concern, particularly in soil with cobbles or boulders. However, installation experience through cobbles and boulders has been positive. The hammering effect tends to break up the boulders or force them out of the path either to the outside or inside of the casing.

Transportation Agency Practices

Responses to the survey questionnaire from DOTs indicated a high level of acceptance for PR, although most DOTs do not have written specifications or guidelines. The responses indicated some confusion between PR and PJ methodologies. In a telephone interview, a contractor expressed concern about Florida DOT's reluctance to approve PR for long drives in wet soils because of the uncertainty about being able to pinpoint the location of the end of the steel casing at all times and the inability to steer it. This reluctance, however, is completely justified, especially if the depth of cover is shallow. PR is not intended for use on long drives. The typical range of application for PR is 30 to 60 m (100 to 200 ft).

Emerging Technologies

PR is a proven installation technique that emerged from the impact moling process. It has evolved from a method for installing small-diameter steel conduits to a method suitable for installing large-diameter steel pipe. Such installation is possible because of the development of larger percussive hammers and the application of methods to manage and reduce the frictional forces that develop along the outside surface of the casing pipe. The main area of needed improvement is controlling the impact force required to drive the steel pipe. Therefore, the focus of emerging technology will be in developing more effective casing lubrication systems and methods to remove soil from inside the pipe during installation. In addition, methods to locate and steer the steel casing as it is being installed must be developed for longer drives.

Case Studies

The following three case studies demonstrate the typical application and capability of the PR process:

Case Study 1

PR was the method selected to install a steel gasoline product pipe 915 mm (36 in.) in diameter beneath heavily traveled Highway 77 east of Birmingham, Alabama. The new pipe was specified to have a concrete exterior coating 50 mm (2 in.) thick and was designed to replace an existing 915-mm (36-in.) carrier pipe installed inside a steel casing pipe that had developed cathodic corrosion between the casing and carrier pipe.

Grade control was a major concern for this 27-m (90-ft) crossing because of unstable soil conditions created by groundwater, which is supplied by a spring near the front of the drive shaft. The drive shaft required continuous pumping of the soft muck. The PR crew stopped three times during the first 3 m (10 ft) and cleaned out the casing to check line and grade. The required 27 m (90 ft) was installed with only a drop in grade of 150 mm (6 in.). A 300 mm/min (12 in./min) penetration rate was achieved by using only one-fourth of the rated power of the impact hammer.

Case Study 2

PR was selected to install 43 m (140 ft) of steel casing pipe 762 mm (30 in.) 11 m (35 ft) beneath Highway 352 in Media, Pennsylvania. The installation, including field setup, PR, equipment removal, and site restoration, was completed within 2 workdays. The average penetration rate was 46 mm/min (18 in./min). Compressed air was augmented with bentonite slurry to force the soil from inside the casing pipe).

Case Study 3

PR was selected to install 30 m (100 ft) of steel casing 1,525 mm (60 in.) 5.5 m (18 ft) beneath double mainline railroad tracks that carry approximately 20 trains per day. Original soil data indicated that cobbles would be smaller than 150 mm (6 in.); however, drive shaft excavation revealed boulders 1.5 to 2 m (5 to 6 ft) in diameter. Soil conditions consisted of wet, flowing, granular materials. The original method selected was auger boring; however, the contractor decided to use open-face PR because of the presence of boulders. Boulders as large as 1,220 mm (48 in.) passed through the casing as it was being rammed. Larger rocks were drilled and split with rock splitters, with pieces being pulled through the casing with a winch and cable. An auger was used to remove the soil from inside the pipe.

CHAPTER SEVEN

SOIL COMPACTION METHODS

Soil compaction (SC) methods are trenchless methods for new conduit installation in which a soil bore hole is formed by in situ soil displacement through the use of a compacting device. SC methods include nonrotating push-rod thrust boring, rotating thrust boring, and impact moling. A compacting tool is forced into the soil by applying either a static thrust force or dynamic impact energy, and the soil along the line is simply displaced rather than removed.

In general, soil compaction (SC) methods are referred to as thrust boring and impact moling. In thrust boring, a compaction bit is connected to a string of pushing rods, which transfers the thrust force from a power source. In impact moling, a self-propelled down-hole hammering device or "earth piercing tool" is used. Work is under way to integrate these two methods into a single method for improved performance (*67*).

Description

Thrust Boring

Thrust boring, or rod pushing, is one of the simplest methods in trenchless construction. Many technical improvements that greatly enhance its capacity have been made. Thrust boring usually is conducted between two access shafts. A horizontal pilot bore is made by thrusting a pointed, conical-shaped compaction head through the soil using a string of solid rods. The back end of the rod string, connected to a hydraulic or other power source located in the drive shaft, pushes the string forward. The push string is formed by connecting a series of short rods. The diameter of the head usually is slightly larger or equal to that of the push rods. When the compaction head reaches the reception shaft, it is replaced with a swivel for pulling utility lines through. A reaming device can be used during the pullback process to enlarge the pilot bore. The new pipelines also can be jacked into place as the rods are retracted.

The power source or rod pushing machine can be as simple as a backhoe bucket. However, in most cases, a specially designed hydraulic thrust frame is used for increased efficiency and accuracy. The capacity of some jacking frames is 445 kN (100,000 lb). The basic operating mode is to push the compaction head without rotating or impacting. The soil penetration process of the compaction head can be improved by rotating in addition to pushing the rod string. The rotational effect combined with a compaction head with a pseudo-slanted face also allows the steering technique, used widely in directional drilling methods, to be adapted to thrust boring systems. By controlling the rotating and nonrotating status of the compaction head, a desired curved path can be bored. The steering capability also can be used on a nonrotating thrust boring system by use of a retractable bevel nose section.

Impact Moling

In impact moling, a small soil cavity is formed using a self-propelled down-hole hammering or piercing tool. Such a tool normally consists of a long hollow cylinder housing with a conical-shaped displacement head at the front and a percussion piston inside (Figure 28). The piston is connected through a flexible hose to an outside pneumatic or hydraulic power source, which causes the reciprocating movement of the piston along the axis of the cylinder housing at a rate of about 400 to 600 strokes per minute (*7*). The energy transferred from the piston strokes causes the impact action of the displacement head on the soil and the dynamic forward movement of the piercing tool. The process forms a cavity in the soil. The soil is compacted and displaced into the surrounding space. In addition to the self-propelled feature, many piercing tools are equipped with a reversal capacity, which allows the withdrawal of the tool from far inside the soil in case unexpected obstacles are encountered or the bore has seriously deviated from the desired path.

The field operation usually is conducted from a start pit to a target pit. To ensure accurate alignment, the piercing tool is launched using a stable starting cradle equipped with an aiming frame (Figure 29). The new cable or pipeline casing can be installed immediately following the hammering tool by pulling or jacking. In stable soil conditions, the new line can be installed after the pilot boring is completed. Normally, the flexible hose for transmitting power cannot be used for backreaming. The bore hole diameter is limited to that of the piercing tool's cylinder housing.

Main Features and Application Range

Field operations typically require small working shafts and may result in slight surface disruptions. SC methods do not require spoil removal to form the bore hole, thus eliminating the problem of spoil disposal. This is particularly useful for applications in contaminated soil zones.

The effectiveness of soil displacement depends on soil properties and characteristics such as compressibility, grain size, and gradation. The presence of a high water table may affect soil compressibility. Generally, compressible soils such as unconsolidated soft silt or clay, mixed-grain, or well-graded soil with a high void ratio are most favorable for soil displacement methods. Poorly graded or dense soils are difficult to pierce.

Except for a recently developed directional thrust boring method, most soil displacement systems lack directional control capability. This limitation restricts their application to

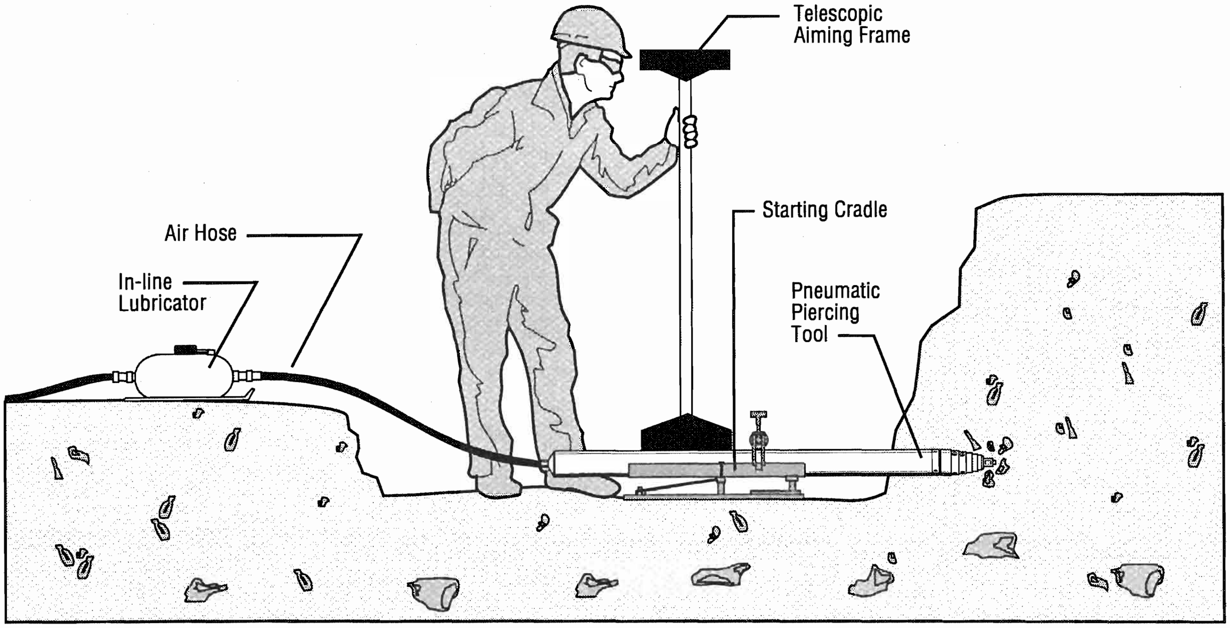


FIGURE 28 Impact moling process.

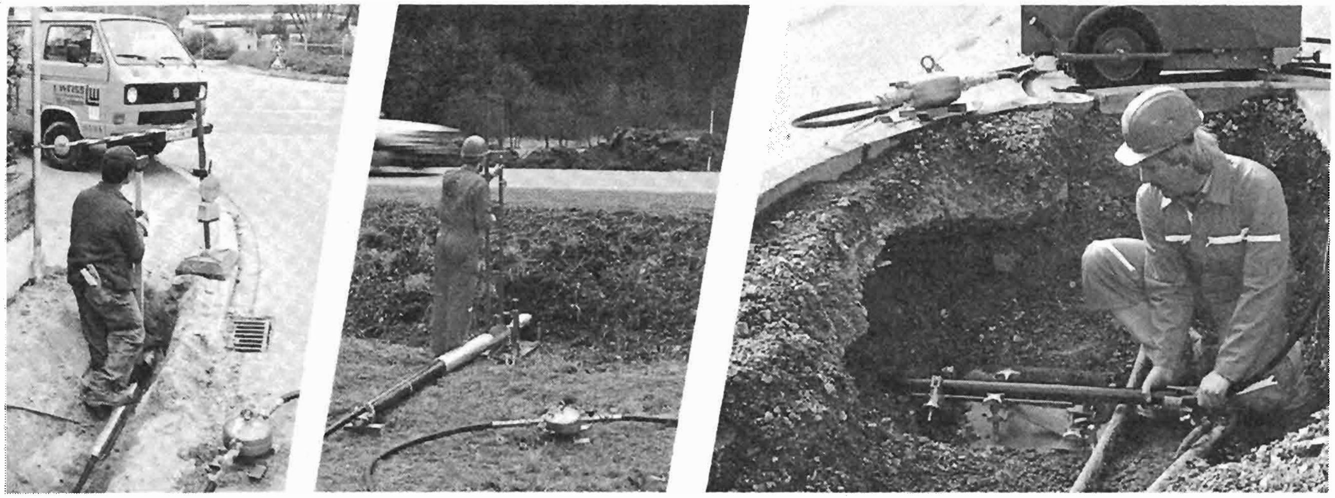


FIGURE 29 Alignment of impact moling tool: *(left)* crossing underneath a road junction with minimum ground cover; *(center)* crossing underneath a road without impeding traffic flow; *(right)* intercity crossing without traffic disruption.

short distance bores. The typical bore length ranges from 12 to 24 m (40 to 80 ft). Currently, SC methods are used for installing small pipelines and cables with diameters up to 300 mm (12 in.). These methods have become popular for installation of telecommunication cables and residential service connections because of the simplicity of their equipment and operation.

Productivity Issues and Special Concerns

Both thrust boring and impact moling involve simple operations. Normally, a crew of two can perform the installation. The rod pushing operation, which advances fast, is similar to driving the drill rod in the directional drilling process. Although down-hole percussion tools typically advance at a rate of 75 mm to 1.2 m (3 in. to 4 ft) per minute, the rate depends on the displacement head configuration and soil conditions. Selection of the proper type of head configuration is a matter of balancing the desired advancing speed and boring stability. Average speeds of 10 m/hr (33 ft/hr) are attainable in normal soils. In soft soils, the tool tends to lose traction, making it necessary to reduce speed and boost the forward motion of the tool by applying additional static pressure.

For nondirectional soil displacement methods, the accuracy of the installation is largely determined by the initial setup. However, there is always a tendency for the head to take the path of least resistance in nonhomogeneous soils. This must be considered during the project planning phase.

The requirement for minimum soil cover depth, which typically is 250 mm (10 in.) of depth for each 25 mm (1 in.) of tool diameter, should be observed to prevent surface heave, because soil displacement tools introduce extra volume into the soil. In unconsolidated loose soil, dynamic impact energy results in compaction of the soil, which may result in surface subsidence. In all instances, provisions should be made to avoid damaging utility lines in the vicinity.

Operations involving a percussion tool may be noisy, and this aspect should be evaluated for use in residential or other sensitive neighborhoods.

Transportation Agency Practices

As is the case with other trenchless technologies, limited information exists on current DOT practices regarding SC methods. The following summarizes some highway agency practices obtained from the literature and the survey conducted for this study:

Most state highway agencies that responded to the questionnaire expressed concern about large impact moling. These concerns centered around the effect of dynamic action and SC on adjoining utilities and pavement structures. Theoretical and experimental research is currently under way in the United States and Europe to predict ground movement under various soil conditions (*68–71*). The results of this research should help alleviate some of the concerns and help gain wider acceptance for SC methods in roadway crossings.

Colorado DOT

A small pipe with a pilot shoe can be driven through compressible soils by a steady thrust, hammering, or vibrating. A casing or corrosion-resistant carrier must be used. Care should be taken to ensure that drives do not deviate excessively from desired line and grade.

Florida DOT

Compaction methods are not allowed for crossings requiring casings whose outside diameter is greater than 125 mm (5 in.).

Michigan DOT

Static compaction auger operation, consisting of augering a rotating stem under the roadway while pulling back a series of graduated cones that squeeze the soil to a desired diameter bore hole, is approved for use. Dynamic methods (i.e., those requiring piercing tools and impact moles) require special authorization. Approval of dynamic methods is done on a case by case basis.

New York State DOT

Any method that consists of installation of pipes more than 100 mm (4 in.) in diameter and that does not have a spoil removal system is not permitted. For pipes 100 mm (4 in.) or less in diameter, special approval by the regional traffic engineer is required.

North Carolina DOT

Acceptable methods include rotary rod pushing and driving a tool no larger than 150 mm (6 in.) through compressible soils by a steady thrust, hammering, or vibrating.

Oregon DOT

When driving or moling through ground, disturbance to the surrounding material should be kept to a minimum.

Emerging Technologies

Most SC tools are capable of directional steering. By incorporating a rotating, unsymmetrical, conical-shaped head and associated direction sensing and controlling devices into a down-hole impact tool, a desired boring path can be followed. It has been proven that boring efficiency can be increased by mounting the impact tool on the front of a string of push rods (*72*). These technical improvements allow the impact tools to bore longer spans at higher rates and to install large pipes or cable lines through a reaming process. In some systems, bentonite slurry is used to cool down the hammer and keep the bore hole stable.

A new guided impact mole has been developed under the sponsorship of the Gas Research Institute (GRI) and is currently undergoing field trials. Commercial introduction of this system is expected in 1997.

Standard soil displacement methods will remain cost-effective alternatives for short-distance bores for utility installations. More sophisticated systems equipped with directional capability will compete with small directional drilling systems. It is expected that down-hole hammering tools will have more potential for rock boring.

Case Studies

As reported by Johnson (*73*), in March 1996, the Pennsylvania American Water Co. assembled nine crews and armed them with piercing tools to connect approximately 450 new services. The initial soil investigation indicated that the ground was mostly clay, occasionally mixed with rock. As crews began to prepare the entry area, they discovered that the sand and clay soil was peppered with an unusually high concentration of rock. The first piercing tool was launched from an entry pit to make a 7.5-m (25-ft) bore hole.

The crew then moved over to the other side of the road to prepare the exit area. There, they quickly discovered a solid shelf of limestone. A jack hammer had to be used to create an exit area for the tool. The piercing tool was left to continue boring to test its tenacity. At approximately 7 m (23 ft) from the launch pit, the progress of the tool had slowed dramatically. Finally, 22 hr from the time the tool was launched, it broke through on the other side. The reciprocating chisel tip of the tool functioned like a pneumatic hammer to break through the limestone. Under normal circumstances, a 7.5-m (25-ft) bore hole in favorable soil conditions can be completed in less than a half hour.

This case study illustrates the versatility of piercing tools. The type of soil is not critical to this type of operation, and piercing tools can overcome even the most adverse types of soils.

CHAPTER EIGHT

UTILITY TUNNELING

Utility tunneling differs from general tunneling by the tunnel's size and use. Utility tunnels are primarily conduits for utilities rather than passage for pedestrians or vehicular traffic. Although the methods of soil excavation for utility tunneling and pipe jacking (PJ) are similar, there is a difference in the lining used in these techniques. In PJ, the pipe is the lining; in utility tunneling, special steel or concrete liner plates, wood box tunnels, steel rib and wood lagging systems, or the New Austrian Tunneling Method (NATM) are used to provide temporary ground support.

Utility tunneling is the process of constructing underground utility passages by removing excavated soil from the front cutting face and installing a liner to form a continuous ground support structure. All current trenchless tunneling methods require person-entry operations inside the lining during the tunneling process. However, with advances in robotic technologies, it is expected that a new non-person-entry utility tunneling approach for small-diameter tunnels will evolve by the turn of the century.

Description

A utility tunnel is normally constructed and lined under the ground surface between two access shafts. Excluding preparation work, such as pit construction and field setup, a typical utility tunneling procedure consists of four major steps: (1) soil excavation, (2) soil removal, (3) segmental liner installation, and (4) line and grade control. The completed tunnel sometimes is lined with a secondary or permanent liner of cast-in-place concrete, or a smaller pipe may be encased in the tunnel as the product pipe. Figure 30 illustrates the typical components and setup of a utility tunneling operation.

Soil Excavation

Depending on soil characteristics, soil excavation can be accomplished by hand mining, open-face mechanical excavation, closed-face tunnel boring machines (TBMs), or NATM. Figure 31 presents an inside view of a TBM.

Hand mining, the simplest form of soil excavation, is conducted at the face using picks, shovels, or pneumatic handheld tools. A protective shield, which may have a forward hood projection to provide additional face stability during soil excavation, usually is required. In an articulated shield, line and grade corrections can be accomplished by activating the hydraulic propulsion cylinders. In a fixed shield, minor line and grade changes are accomplished by differential excavation in the desired direction.

When a high underground water table is present, compressed air can be applied to prevent or minimize groundwater

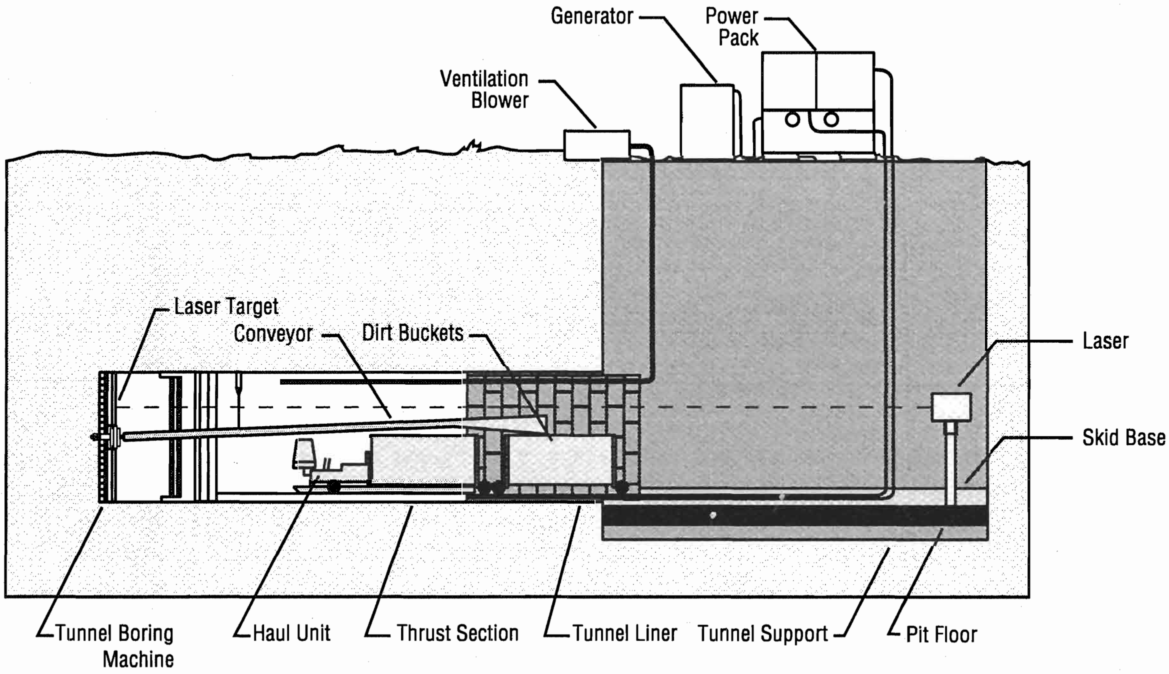


FIGURE 30 Typical components of utility tunneling system.

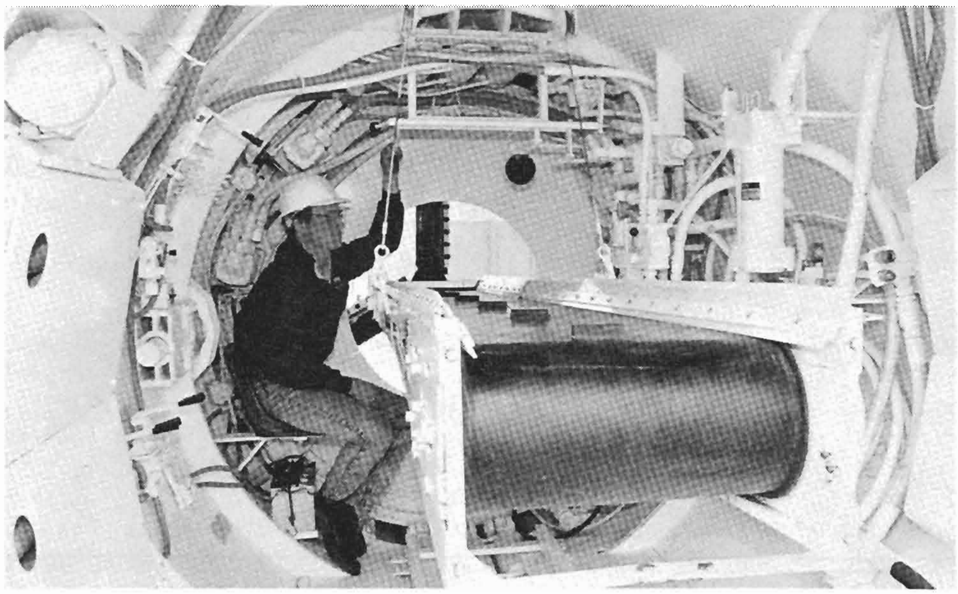


FIGURE 31 Inside view of tunnel boring machine.

inflow. Compressed air, however, is being used less frequently because of health and safety considerations.

Generally, hand mining operations are slow and therefore limited to short drives; however, hand mining provides simplicity and the versatility to handle difficult and varying soil conditions. In addition, hand mining requires minimal work space and can be used to install linings as small as 760 mm (30 in.) in diameter.

Open-face mechanical excavation is accomplished by using special shields equipped with power excavation devices. Such soil cutting devices can be rotary cutter booms mounted on the front of the shield, modified hydraulic backhoes, or rotary boom cutters. Combinations of these devices also are used for soil cutting. In case of unstable soil conditions or a high underground water table, compressed air sometimes is used, and in some shields, the tunneling operator is not required to work inside the pressurized zone. Most open-face shields still provide personnel with access to the front face if the need arises. This facilitates the on-line adjustment of cutter head configurations to accommodate varying ground conditions as well as the manual handling of unexpected obstructions. The soil excavation rate of open-face mechanical excavation is much faster than that of hand mining.

Closed-face tunneling shields are referred to as TBMs when equipped with hydraulically or electrically driven rotary cutter heads or disk cutters. Soft-ground TBMs sometimes are referred to as shield machines. The cut soil is forced inside the shield through slits or other openings in the cutter head as the shield is advanced. Generally, closed-face TBMs provide better face stability during soil excavation and thus are most suitable for noncohesive soils below the water table. However, in practice, they have much wider applications. Some systems have crushing devices to cope with gravel and boulders. The major drawbacks of typical TBMs include relatively high cost, limited face access, and the fact that they only can be used to install circular tunnels.

More sophisticated TBM systems incorporate a pressure chamber that provides a balance between the soil face pressure and external water pressure. Such systems have been adopted more commonly in non-person-entry microtunneling methods.

The *New Austrian Tunneling Method* (NATM) has been used in the United States mostly for soft-ground tunneling. The basic principle of NATM is to allow the ground surrounding the tunnel to deform just enough to mobilize its shear strength. Frequently, this limited deformation is achieved by using a flexible tunnel support system constructed of a combination of steel ribs or rock bolts, wire reinforcement, and shotcrete. This method requires the use of design and construction monitoring and supervision specialists (*74*).

Spoil Removal

There are six approaches for conveying excavated spoil from the face back to the start pit for disposal (*75*). These spoil conveyance systems are as follows:

- Wheeled carts or skips
- Belt and chain conveyors
- Positive displacement pumping devices
- Slurry systems
- Auger systems
- Vacuum extraction systems.

Selection of an appropriate spoil removal system is determined by the space inside the tunnel, the method of soil excavation, and the mechanism of the face pressure balance and total tunnel length.

Steering Control and Tunneling (Shield) Advancement

Theodolite and laser systems for directional measurement are the two most common approaches for achieving steering control and tunneling advancement. The theodolite is a classic surveying instrument that can monitor the current position of the tunnel face directly. The equipment cost is low; however, the surveying process requires a skilled operator and a source of light and cannot be used for continuous monitoring because it causes temporary interruption in the tunneling work.

A laser monitoring system allows any directional variation to be adjusted immediately. However, the laser beam is sensitive to temperature variations along the line and might become dispersed over a long distance of dusty air. Sometimes the combination of laser and theodolite methods yields more satisfactory results. More sophisticated inertia surveying systems, such as the gyroscope, have been adopted for curved tunneling.

Steering control is accomplished during the soil excavation and shield advancing process. A minor direction change is much easier to accomplish when no protection shield is used under stable soil conditions. A tunneling shield usually is equipped with a few jacking cylinders at its rear portion, which propel the shield forward by jacking against the already erected liner sections as face excavation proceeds. These jacking cylinders can apply different forces and extend at different speeds during one forward tunneling cycle to correct the direction of the shield. After the shield has advanced a certain distance, the jacks are retracted to leave room at the rear of the shield (i.e., the protective tail section) for the in situ installation of the new liner system.

Liner Installation

After the soil face has been excavated and removed or the shield is advanced and the jacking cylinders are retracted, new segmental liners are transported through the erected lining to the face. These liners are erected in situ and connected to the existing lining. If a tunneling shield is used, the retracted jacking cylinders are extended and make contact with the front profile of the new lining. This completes a single forward tunneling cycle. This procedure is repeated until the tunnel has reached the target location. In the case of tunneling through rock formation, there might be no need for a lining.

The currently used liner materials are prefabricated liner plate/segments and steel rib and wood lagging systems. Liner plates/segments typically are made of steel or precast reinforced concrete. The steel liner plates have flanged edges that allow the overlapping and bolting together of successive liner plates to form an integrated lining. Some concrete segments are bolted together through precast holes; others are unbolted. Steel plates are used more widely for utility tunnel applications because their strength-weight ratio is higher than that of concrete plates. Typically, liner/segment ground support systems require grouting of the annular space outside the liner/segment. Prefabricated grout application holes often are installed in the liner/segment. Steel rib and wood lagging tunnel liner systems can be designed so that the liner can be expanded against the ground just outside the shield tail section, thus eliminating the need for grouting.

Main Features and Application Range

In utility tunneling, the lining is formed by in situ installation of segmental liners, and the tunneling shield, if used, is the only portion that is jacked forward along the entire tunnel length. The required jacking force is relatively small, and theoretically there is no upper limit for the length of a single-pass tunneling process. Because personnel access normally is available during the tunneling process, these methods are suitable for various soil conditions, and ground stability usually can be well controlled. High accuracy in steering is achievable, and curved tunnel alignments can be easily accommodated. However, utility tunneling's main disadvantage is that the temporary support or original tunnel lining cannot serve as the final carrier pipeline that must be installed inside. The annular space between the two must be grouted.

Although theoretically it is possible for a person to enter a pipe 915 mm (36 in.) in diameter, from a practical standpoint, it is very difficult for a person to work in this environment for any extended period of time. Hence, the minimum tunnel diameter recommended is 1,000 mm (42 in.). For longer drives, the recommended diameter is 1,220 mm (48 in.).

Productivity Issues and Special Concerns

Although remote control of many elements of the tunneling process has been realized in recent years, the installation of segmental liners almost always requires manual operations. However, these systems have become more automated. Generally, utility tunneling is a relatively slow and labor-intensive process. The actual tunnel advance rate is determined by soil conditions encountered, the method of soil excavation and removal, liner materials, and the field coordination and skill level of tunneling personnel. Productivity will be reduced greatly if compressed air must be used. Also, because the tunneling operation requires personnel with a high level of skill and coordination, a long learning curve is expected when difficult ground conditions are present. Therefore, the length of the tunnel is an important factor influencing the overall advance rate.

Transportation Agency Practices

Tunneling has a long history and, consequently, is a widely accepted technique for installing pipelines under roadways. Almost all the highway agencies surveyed have guidelines and specifications for tunneling under roadways.

Some unresolved issues, however, do remain. Certain concerns were expressed by the highway agencies about potential ground movement caused by the voids between the lining and surrounding soil. Although it is generally believed that such annular voids should be grouted, there seems to be a lack of accepted guidelines indicating when the grouting should take place.

Emerging Technologies

Utility tunneling techniques are well established because contemporary tunneling practice dates back 200 years, when the first tunneling shield was invented. New technologies have enabled the remote control of more efficient TBMs and powerful pumping devices to facilitate spoil removal over long distances. Gyroscopic steering systems are being developed to provide more dependable direction control for long distance and curved-alignment drives. A patent application is being processed for a non-person-entry remote controlled tunneling technique. This process will bring all the advantages of tunneling to pipeline construction applications of smaller sizes.

Besides conventional liner materials, a few new materials and configurations of segmental liners that can be used as permanent linings and that can shorten the labor-intensive liner installation process are under development.

Case Study

As reported by Kolitsch (*76*), as a part of the Washington Metropolitan Area Transit Authority's Green Line Metro project, a utility tunnel 2.1 m (7 ft) in diameter was constructed using NATM. The NATM section of the tunnel is approximately 119 m (390 ft) long. Soil exploration revealed two major strata: Stratum P1 (plastic clay) and Stratum P2 (sand with some gravel). Stratum P1 is a stiff, hard plastic clay with preconsolidation stresses of the order of 718 kPa (15 ksf) and a shear strength averaging 192 kPa (4 ksf). Stratum P2 is a very dense, coarse sandy gravel that occurs frequently at the interface between clays and overlying sands. Groundwater was encountered above the invert.

An initial reinforced shotcrete lining 178 mm (7 in.) thick was installed to maintain the inherent strength of the soil and to act as a thin tube inseparable from the surrounding material. This was followed by installation of a permanent cast-in-place concrete lining.

The shotcreting operation consisted of four stages:

1. A layer of sealing shotcrete roughly 25 mm (1 in.) thick was placed immediately after excavation on the exposed surface to seal and protect the material from loosening and deteriorating.
2. A lightweight, curved steel lattice member was installed after each excavation round to provide intermediate support.
3. Welded wire fabric was installed to reinforce the shotcrete shell.
4. Additional shotcrete was applied to the wall for a total lining thickness of 178 mm (7 in.).

The guidelines required that the contractor perform a tunnel roof presupport measure before performing the NATM excavation. The contractor used horizontal directional drilling (HDD) technology to successfully carry out the first directional drilling, chemical grout soil stabilization program in the United States. Using an HDD machine, nine steel pipes 50 mm (2 in.) in diameter were installed above the crown of the tunnel segment (Figure 32). Because of tight tolerance requirements, high-precision surveys with gyroscope-based tools were conducted periodically to control alignment. A chemical solution of sodium silicate was injected through the tubes into the ground to increase strength and reduce permeability. The grouted soil exhibited an unconfined compressive strength in the range of 520 to 1,040 kPa (75 to 150 psi). During mining, the roof was stable, yet was readily excavated by a modified hydraulic backhoe.

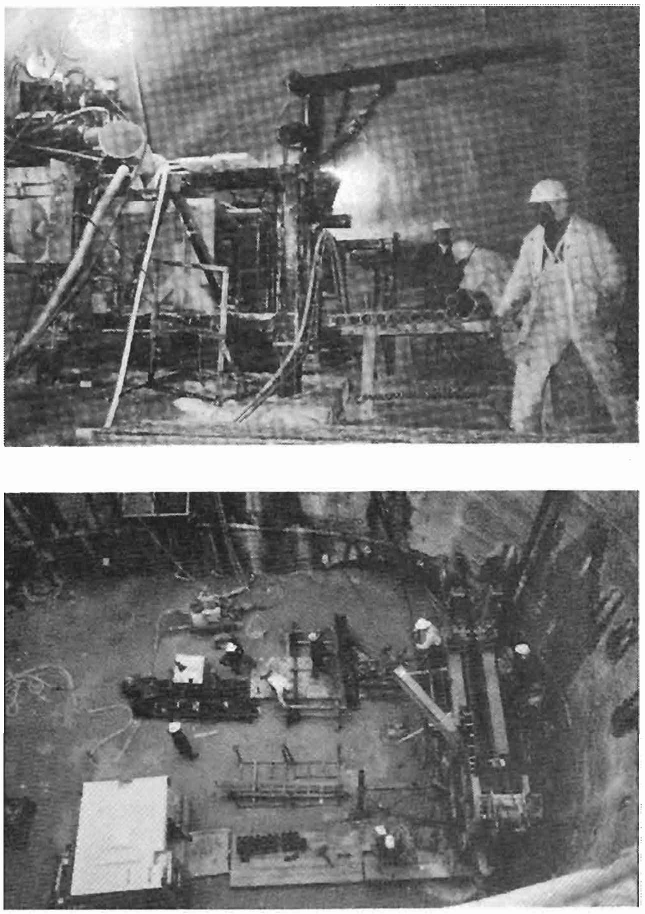


FIGURE 32 Use of horizontal directional drilling (HDD) for strengthening utility tunnel roof *(76)*: *(above)* HDD rig performs grout drilling inside the drill chambers; *(below)* view from top of shaft looking at HDD rig and survey hut. Top portion of the tunnel portal can be seen in the upper left and right.

A wet-mix shotcrete application was used because of its inherent advantages: (1) less rebound, (2) less dust, (3) controlled water dosage, (4) high compressive strength, and (5) improved production and consequently improved economy. Steel fibers and other advanced admixtures can be used with wet- and dry-mix shotcrete. The drawbacks with the wet-mix method were (1) limited conveying distance, (2) increased demand on aggregate quality, and (3) increased cleaning costs *(76)*.

CHAPTER NINE

SUMMARY

The trenchless technology (TT) industry has expanded from the use of basic road boring techniques to a full range of techniques with highly advanced capabilities for installing complete, complex underground utility systems with minimum excavation. Considerable development in TT has taken place in the past 2 decades. By all indications, TT development will increase in the future. This will present major challenges to those who specify and stand to benefit from this technology. These challenges include keeping current with the state of the art (i.e., discovering what works and what does not work) and developing design and construction guidelines that result in the best solution for a particular application.

The challenge of staying current with TT is not unique to state DOT personnel. Transportation, communication, utility and public works personnel, and their consultants need to be knowledgeable in proper construction techniques. Approximately 27 percent of the 71 transportation agency representatives who responded to the survey indicated that they have received some TT training. This training varies from a 3-hr demonstration sponsored by a contractor or equipment manufacturer to an 8-hr American Society of Civil Engineers (ASCE) seminar to a 32-hr operators' training school. Figure 33 illustrates the training transportation agency personnel have received.

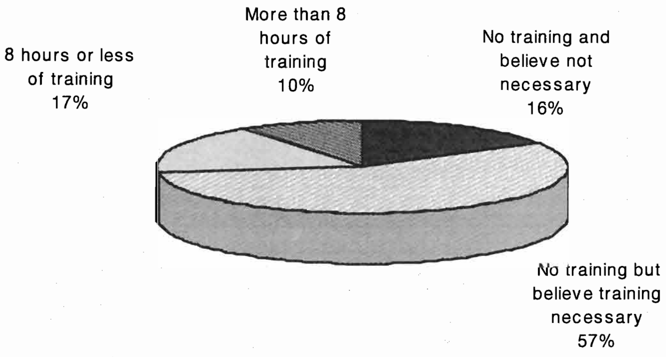


FIGURE 33 Training on trenchless installation techniques received by state and province DOTs.

Fifty-seven percent of the 71 respondents indicated that they have received no TT training and believe that there is a need for training in the selection and use of TT methods. Sixteen percent of the respondents have received no training and believe that training is unnecessary. The most common reason for this belief is to place the responsibility and liability on the shoulders of the owner of the utility installing the crossing. This is not surprising because most roadway crossings are accomplished by utility owners after obtaining a DOT permit.

It is important to ensure that specifications and guidelines for installing conduits under roadways are complete, effective, and current. Figure 34 illustrates the number of state and province DOTs that provide some type of specifications for specific TT techniques. Many survey respondents indicated that they were in the process of reviewing and updating specifications and guidelines for trenchless installation methods.

During the development of this synthesis, it was determined that numerous trade and professional organizations are in the process of reviewing and upgrading specifications and guidelines for trenchless installation methods. For example, one of the primary objectives of the North American Society for Trenchless Technology (NASTT) is to provide a forum, with a balance of all industry segments, to facilitate specification and guideline development. The National Utility Contractors Association (NUCA) has provided excellent specification guidelines and training support. The American Railway Engineering Association (AREA) is aggressively upgrading its TT specifications. AREA representatives have attended training sessions to ensure that their revised specifications are effective and current. The American Society of Civil Engineers (ASCE) has three committees developing codes, standards, and construction guidelines for various areas of the TT industry.

Public safety is put at risk when underground utilities intersect with transportation systems. This risk can be managed and minimized by ensuring that only TT techniques that are compatible with the parameters of each project are permitted. Protecting public safety is, without question, the responsibility of DOTs.

There is no single TT method that is the best for all types of crossings. Site conditions and constraints as well as the purpose of the crossing must be considered when a TT method is selected and permitted. A fully access-controlled highway presents different risks and liabilities from urban roads and streets and even limited access-controlled highways. Understanding site conditions requires surface and subsurface investigations. Accurate, sufficient subsurface data that describe anticipated conditions throughout the bore-hole length should be required. Recommended professional standard practices should be used to obtain subsurface data and communicate these data to contractors.

The DOT representatives indicated that problems are common when conduits beneath roadways are installed with TT methods. The most common problems are as follows:

- Sinkhole/subsidence occurring in the roadway during the boring operation;
- Pavement heaving;
- Casing or drill stem drifting too far off line and grade;
- Drilling fluids migrating to the surface, often under the pavement, causing pavement buckling; and
- Drill stems, piercing tools, and end of steel casing pipe prematurely exiting through the surface, often through the pavement.

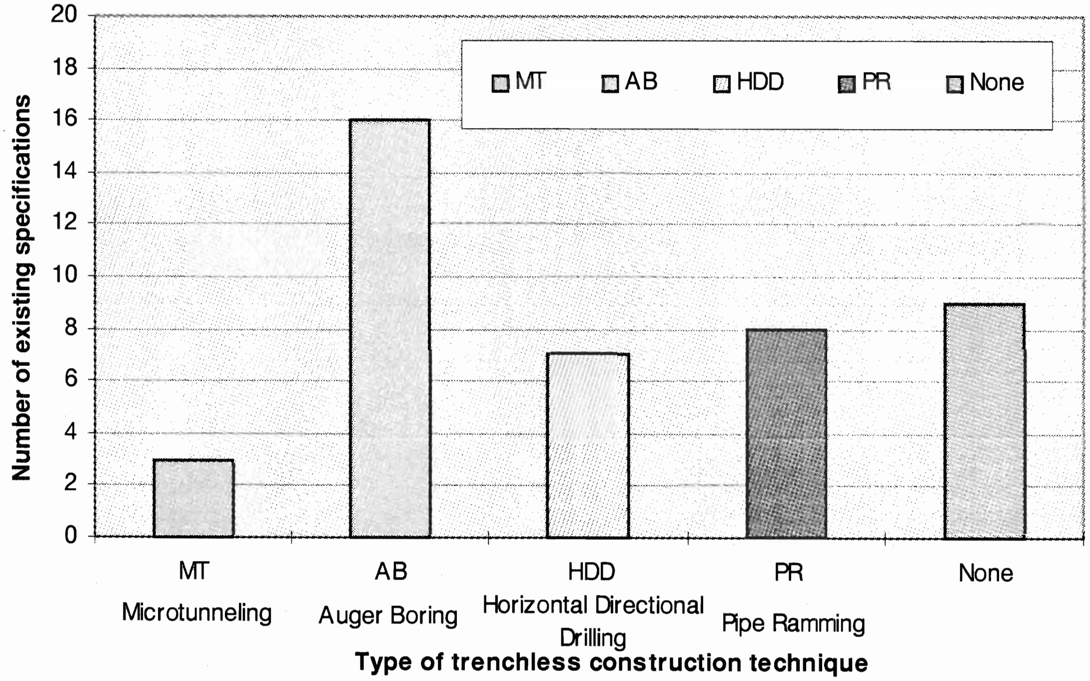


FIGURE 34 Number of existing specifications for trenchless installation techniques in states and provinces.

These types of construction problems present a risk to public safety. With the technology that is available and widely used in the TT industry, these types of problems should be minimized. They can only be minimized, however, by using equipment that is compatible with actual soil conditions. Minimizing public risk requires a commitment to ensure that those involved in the design, permitting, inspection, and construction process are properly trained and equipped with effective specifications and guidelines.

Historically, state DOTs have assumed the role of administrators for the installation of conduits beneath roadways. Because they do not own the utility, DOTs review permit applications, issue permits, and provide on-site inspection services. This role may change in the future as the intelligent highway program gains momentum. This program is expected to require DOT installation of numerous communication cables to operate the intelligent sensors and signals. This need will force DOTs to develop TT specifications and guidelines.

Both the owner of the utility and the owner of the transportation system are concerned about managing assets. If the utility intersects the roadway, conflicts of interest may result. For example, it may be cost-effective from the utility's perspective to open-cut a roadway to install a conduit beneath it; however, the transportation system owner needs to consider the impact that this might have on the following:

- The life of the pavement
- Business
- Performance
- The probability of accidents
- The environment.

Use of TT construction methods for installing conduits beneath roadways will increase. DOTs are responsible for managing and maintaining transportation assets. This requires regulating how conduits will be placed beneath roadways, whether owned by the utility company or the DOT.

Table 8 presents an overview of TT methods. The table provides the following information on each method: (1) the primary application, (2) range of applications (i.e., depth, length, and diameter), (3) type of pipe that can be used, (4) accuracy, (5) working space required, (5) operator skill required, and (8) chief limitations. Table 9 illustrates the compatibility of the methods with various soil conditions. Table 10 presents the costs associated with each method.

TABLE 8

OVERVIEW OF TRENCHLESS METHODS

		Range of Applications				
Method	Primary Application	Depth	Length	Diameter	Type of Pipe	Accuracy
Auger Boring (AB)	Crossings (All Types)	Varies	12–150 m (40–500 ft)	200–1500 mm (8–60 in)	Steel	Medium
Microtunneling (MT)	Sewer Installations	Varies	25–225+ m (80–750+ ft)	250 mm–3+ m (10 in–10+ ft)	Steel, RCP, Fiberglass, GFRP, DI, VCP, PVC	High
Maxi & Midi Horizontal Directional Drilling	Pressure lines, water, gas, cable	< 50 m (160 ft)	120–1800 m (400–6000 ft)	75–1370 mm (3–54 in)	Steel, HDPE	Medium
Mini-Horizontal Directional Drilling (Mini-HDD)	Pressure lines, water, gas, cable	< 15 m (50 ft) with walkover system	12–180 m (40–600 ft)	50–350 mm (2–14 in)	Small diameter steel pipe, HDPE, DI, PVC, Copper service lines, cable	Medium
Steerable Impact Moling	Pressure lines	Min. of 12 mm/mm dia (1 ft/in dia)	12–60 m (40–200 ft)	50–200 mm (2–8 in)	Any pipe material, cables, service lines	Medium
Non-steerable Impact Moling	Small diameter services	Min. of 12 mm/mm dia (1 ft/in dia)	12–30 m (40–100 ft)	50–150 mm (2–6 in)	Any pipe material, cables, service lines	Low
Pipe Ramming	Crossings	Varies	12–60 m (40–200 ft)	100–1070 mm (4–42 in)	Steel	Low
Pipe Jacking (PJ)	Sewers, Pressure lines, Crossings	Varies	No theoretical limit–490 m (1600 ft) spans achieved	1060–3050 mm (42–120 in)	RCP, Steel, Fiber glass	High
Utility Tunneling	Sewers, Pressure lines, Crossings	Varies	No theoretical limit	≥ 1060 mm (≥ 42 in)	Cold formed steel plates, pre-cast concrete segments	High

TABLE 8 (Continued)

Method	Working Space Requirement	Compatible Soil Type	Operator Skill Requirement	Chief Limitations
Auger Boring (AB)	Entry & Exit bore pits. Length 8-11 m (26–36 ft) Width 2.5–3.5 m (8–12 ft), room for storing augers, casing etc..	Variety of soils conditions (see Table 9)	High	High capital cost for equipment, high set-up cost (bore pits); can not be used in wet runny sands, soil with large boulders
Microtunneling (MT)	Primary Jacking Pit : 4 m (20 ft) long, 3m (10 ft) wide, smaller retrieval pit, room for slurry tanks, pipe storage	Variety of soil conditions including full face rock and high groundwater head	High to operate sophisticated equipment	High capital cost and set-up costs, obstructions
Horizontal Directional Drilling (HDD)	Access pits not required. Space for set up of rig and drilling fluid tank : 120 m x 60 m (400 ft x 200 ft)	Clay is ideal. Cohesionless sand and silt require bentonite. Gravel and cobbles are unsuitable.	High degree of knowledge of downhole drilling, sensing & recording. Training essential	Requires very high degree of operator skill. Not suitable for high degree of accuracy such as gravity sewer application. Can install only pipes with high tensile strength e.g. steel, HDPE
Mini-Horizontal Directional Drilling (Mini-HDD)	Equipment is portable and self-contained. Requires minimal area	Soft soils, clay and sand. Unsuitable for rocks and gravel	Same as HDD	Accuracy dependent on range of the electromagnetic receiver (≤ 15 m/≤ 50 ft)
Steerable Impact Moling	Bore pit size varies from 6 x 36x 18 in (150 x 900 x 450 mm) to 10 x 30 x 15 ft (3 x 9 x 4.5 m)	Soft to medium compressible soils. Dense soils are unsuitable.	Basic Limited training	Steerable tools are a recent innovation and lack a track record
Non-steerable Impact Moling	Same as Steerable Impact Moling	Same as Steerable Impact Moling	Basic Limited training	Impact tools often get stuck and veer off target requiring abandonment of bore holes.
Pipe Ramming	Large surface area required to accommodate bore pit, excavated soil, air compressor, pipe to be installed, etc.	Almost all soil types. Earthen plug formed at the leading edge of casing preventing soil flowing into pipe.	Fair skill & knowledge required to determine initial alignment, make decisions on open or close faced bore, lubrication requirements etc.	No control over line and grade. A large piece of rock or boulder can easily deflect pipe from design path. Pipe has tendency to drop and/or come up to the surface. For larger pipe diameters equipment cost increases substantially
Pipe Jacking (PJ)	Jacking pit is a function of pipe size. Pit sizes vary from 10–30 ft (3–9 m)	Stable granular and cohesive soils are best. Unstable sand is least favorable. Large boulders cause frequent work stoppage. Method can be executed with any ground condition with adequate precautions.	This is a specialized operation requiring a great deal of skill and training. Line & grade tolerances are usually very tight and corrective actions can be very expensive.	Specialized operation requiring great deal of planning and coordination. High capital cost.
Utility Tunneling	Smaller surface area as compared to PJ due to compactness of the liner system. Access pit size varies from 9 to 25 ft (2.7–7.5 m)	Same as PJ	Same as PJ	High capital and set-up cost. Carrier pipe is required to carry the utility and the space between the carrier pipe and liner has to be grouted to provide adequate support unless a permanent lining system is used.

TABLE 9

APPLICABILITY OF TRENCHLESS TECHNIQUES IN VARIOUS SOIL CONDITIONS

	Soil Type	Cohesive Soils (Clay)			Cohesionless Soils (Sand/Silt)					
Soil and Groundwater	N Value (Standard Penetration Value as per ASTM D 1452)	N < 5 (Soft)	N = 5–15 (Firm)	N > 15 (Stiff-Hard)	N < 10–30 (Loose)	N = 10–30 (Medium)	N > 30 (Dense)	High Ground Water	Boulders	Full-Face Rock
Applications	Auger Boring (AB)	o	•	•	o	•	•	x	≤ 33% φ[1]	≤ 12 ksi
	Microtunneling (MT)	•	•	•	•	•	•	•	≤ 33% φ[1]	≤ 30 ksi
	Maxi/Midi–Horizontal Directional Drilling (HDD)	o	•	•	o	•	•	o	o	≤ 15ksi
	Mini-Horizontal Directional Drilling (Mini-HDD)	o	•	•	o	•	•	o	x	x
	Impact Moling/Soil Displacement	o	•	•	x	•	o	x	x	x
	Pipe Ramming	•	•	•	•	o	o	o	≤ 90% φ	x
	Pipe Jacking (PJ)									
	w/ TBM	o	•	•	o	•	•	o	o	≤ 30 ksi
	w/ Hand Mining (HM)	x	•	•	o	•	•	x	≤ 95% φ	o
	Utility Tunneling (UT)[2]									
	w/ TBM	o	•	•	o	•	•	o	o	≤ 30 ksi
	w/ Hand mining (HM)	o	•	•	o	•	•	o	≤ 95% φ	•

•: Recommended o: Possible x : Unsuitable N/A: Not Applicable

(This table is based on the assumption that work is performed by experienced operators using proper equipment)

[1] Size of largest boulder versus minimum casing diameter (φ)

[2] Ground conditions may require either a closed face, earth pressure balance, or slurry shield.

TABLE 10

COST RANGE FOR TRENCHLESS CONSTRUCTION METHODS (Based on Midwest Cost Indices, 1996)[1,2]

TT Method	Cost Range	Installation Comments
Auger Boring (AB)	$0.40–0.50/D.MM/M ($3–4/D.I/LF)	Line and Grade Not Critical
	$0.50–0.80/D.MM/M ($4–6/D.I/LF)	Line and Grade Critical
Slurry Boring (SB)	$0.15–0.40/D.MM/M ($1–3/D.I./LF)	Line and Grade Not Critical
Microtunneling (MT)	$1.70–2.60/D.MM/M ($13–20/D.I/LF)	Line and Grade Critical
Horizontal Directional Drilling (HDD)[3]		
Maxi	$650–1,650/M ($200–500/LF)	Line and Grade Not Critical
Midi	$160–650/M ($50–200/LF)	Line and Grade Not Critical
Mini	$15–160/M ($5–50/LF)	Line and Grade Not Critical
Soil Compaction	$0.15–0.25/D.MM/M ($1–2/D.I/LF)	Line and Grade Not Critical
Pipe Ramming (PR)[4]	$0.40–0.80/D.MM/M ($3–6/D.I./LF)	Line and Grade Not Critical
Pipe Jacking		
w/TBM	$0.65–1.15/D.MM/M ($5–9/D.I./LF)	Line and Grade Critical
w/Hand Mining (HM)	$0.80–1.90/D.MM/M ($6–15/D.I./LF)	Line and Grade Critical
Utility Tunneling		
w/TBM	$0.80–1.30/D.MM/M ($6–10/D.I./LF)	Line and Grade Critical
w/Hand Mining (HM)	$0.90–2/D.MM/M ($7–16/D.I./LF)	Line and Grade Critical

TBM: Tunnel Boring Machine, D.I.: Per Inch of Pipe Diameter, LF: Per Linear Foot of Pipe, D.MM.: Per 100 MM of Pipe Diameter, and M: Per Meter of Pipe.

[1] Cost includes cost of installation, mobilization, de-mobilization and planning. Does not include casing/carrier pipe material cost, cost for preparing entry/exit pits and shafts, or dewatering costs.

[2] Costs assume good ground conditions (i.e. sandy clay, sand, silt), moist ground, and fairly firm soils (N = 6-20) with shafts < 6 m (20 ft) deep, and bore length > 5 m (50 ft). Does not include mixed face condition or soil with significant rock formation or boulders.

[3] Horizontal Directional Drilling is not so much a function of the pipe diameter as it is the length of the bore for small diameters, e.g. in a Mini-HDD it costs the same to install a 50 mm (2 in) pipe as it costs to install a 150 mm (6 in) pipe provided the length remains the same. For diameters larger than 250 mm (10 in), the cost is a function of both the diameter and length of the installed pipe.

[4] Pipe Ramming requires a heavier pipe to sustain the dynamic loads. this will affect the material costs.

CHAPTER TEN

CONCLUSIONS

Numerous trenchless techniques are available for installing a wide range of types and sizes of utility conduits beneath roadways in a wide range of soil conditions. These techniques vary in complexity and cost. U.S. and Canadian transportation agencies differ in their use and understanding of trenchless construction methods, materials, and equipment.

The concept of installing a utility conduit without digging a trench across the roadway is not new. Traditional pipe jacking has been used for more than 100 years, and auger and slurry boring have been used for almost 50 years. However, the design of transportation systems changed, which increased the typical highway crossing width from 12.2 m (40 ft) to more than 100 m (330 ft). Traffic density has substantially increased the demand for nondisruptive and nondestructive (i.e., trenchless technology (TT)) methods to install utility conduits beneath roadways.

The capabilities of TT methods have expanded rapidly during the past 10 to 15 years. Automation, robotics, computer field data acquisition systems, automatic mapping, remote sensing, and computer processing utilizing artificial intelligence and fuzzy logic are common components of TT techniques. TT requires equipment and personnel skills that are more specialized than those of traditional open-cut technology.

A survey conducted in 1996 of U.S. and Canadian transportation agencies indicated that TT use increased from 1993 to 1995. The survey identified common concerns relating to TT use, including the following:

- Ground movement (i.e., heave or subsidence)
- Accuracy
- Safety
- Traffic disruption.

Survey respondents represented 33 states and 6 provinces. A majority (73 percent) indicated that they had received no training in TT. Those who had received TT training indicated that the training consisted primarily of demonstrations by equipment manufacturers and contractors. This training, which was limited to one or perhaps several techniques, was not comprehensive and tended to be more promotional than educational in nature.

The survey indicated that no state or province DOT had specifications that addressed all the methods covered in this synthesis. Most DOT specifications addressed either auger boring or pipe jacking, and several addressed both. One respondent indicated that his or her agency was in the process of updating its specifications to include all methods.

Following are the major findings from the study:

- No one method is suitable for all types of utilities or all types of soil or site conditions. The selection of compatible methods is site specific and highly dependent on subsurface conditions. Therefore, an adequate soils investigation and an accurate underground utility location program are critical for minimizing subsequent construction problems and claims.
- A majority of the DOT survey respondents indicated that their agencies do not perform trenchless construction projects directly. The work is accomplished by utility owners through a permit process. The number of permits for utility installation beneath roadways varied between 500 and 5,000 per year. The trend within the DOTs was to place the design and construction responsibilities and liability on the utility owner.
- Several DOT survey respondents provided information on trenchless projects that resulted in construction problems. These problems ranged from drilling fluid migrating to the surface and drill stems prematurely exiting through the pavement surface to the development of large sink holes. The respondents emphasized that construction problems are a concern because their agencies are responsible for the safety of the traveling public as well as the integrity of the roadway. As TT use expands, construction problems are likely to increase in number and severity. The severity is likely to increase as a result of more congested and complex applications of TT installations.
- Two resources are essential for minimizing the risk of construction problems associated with the use of trenchless techniques: (1) adequate specifications and guidelines for contractors to follow and (2) adequate training of DOT personnel involved with permitting or inspecting trenchless projects.

The results of this study suggest the following:

- Because all state and province DOTs have a common need to upgrade their specifications, this activity could be coordinated at the national level and adopted at the state and province level.
- A comprehensive TT training program could be developed for state and province DOTs. This program would focus on common problems associated with the use of the various TT methods and how they can be prevented.
- Prequalification criteria could be developed that emphasize the experience level of the operator and crew.
- Guidelines could be developed for encouraging the use of common conduits by utility owners for installations beneath roadways.

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GLOSSARY

Annulus—Free space between the carrier pipe and any lining or the casing pipe and the bore hole.

Artificial Intelligence—Machine or computer capability to perform humanlike functions such as learning, reasoning, and self-control.

Auger—A flighted (helical-wound blades) drive tube, with hex couplings at each end, to transmit torque to the cutting head and transfer spoil back to the machine.

Auger Boring—A technique for forming a bore hole, from a drive pit to a reception pit, by means of a rotating cutting head. Spoil is transported back to the drive shaft by helical-wound auger lights rotating in a steel casing. The steering capability varies from none to full horizontal and vertical control.

Auger String—A set of augers connected end to end to extend from the cutting head to the auger boring machine.

Back Reamer—A cutting head attached to the leading end of a drill string to enlarge the pilot bore during a pull-back operation to provide the means for the carrier, sleeve, or casing to be installed.

Bentonite—A colloidal clay, sold under various trade names, that forms a slurry or gel with high lubricity when mixed with water. Also known as driller's mud or drilling fluid.

Bent Sub—An offset section of drill stem behind the drill head that allows steering corrections to be made by rotation of the drill string to orient the cutting head. Frequently used in directional drilling.

Bore—A hole produced underground. For trenchless technology it is nearly horizontal and used primarily for the purpose of installing utilities. Sometimes referred to as a bore hole.

Bore Hole—See bore.

Clay—Invisible particles less than 0.005 mm (0.0002 in.) in diameter. Cohesive and highly plastic when moist. Will form a long, thin, flexible thread when rolled between the hands. Does not feel gritty. When dry, will form hard lumps or clods that resist crushing. Low permeability.

Conduit—A broad term that includes pipe, casing, ducts, tunnels, and channels.

Cost-Effective Alternative—An alternative utility installation method identified as being the best available in terms of reliability, permanence, and economic considerations. Although costs are an important consideration, regulatory and other considerations may be more important in some instances.

Cover—The distance from the top of the ground (top of pavement, top of ties, and so forth) to the top of the conduit (pipe, casing, and the like) measured vertically.

Cutter Head—The actual teeth and supporting structure attached to the front of the lead auger, drill stem, or face of a tunnel boring machine. It is used to reduce the material that is being drilled or bored to sand or loose soil so that it can be conveyed out of the hole. Usually applies to mechanical methods of excavation, but may also include fluid jet cutting.

Flight—The spiral plates surrounding the tube of an auger.

Fuzzy Logic—Logic that consists of maximum and minimum selection operators. Makes use of membership functions to define level of affiliation to sets of values. A basic term in neural network literature.

Gravel—Rounded or water-worn pebbles or bulk rock grains. No cohesion or plasticity.

Groundwater—The supply of water beneath the earth's surface, usually in aquifers.

Peat—Partly decayed plant material. Mostly organic. Highly fibrous with visible plant remains. Spongy and easily identified.

Remote Sensing—The gathering and recording of information about terrain and ocean surfaces without actual contact with the object or objects that are being investigated. Remote sensing uses the visual, infrared, and the microwave portions of the electromagnetic spectrum. (From McGraw-Hill Concise Encyclopedia of Science and Technology.)

Right-of-Way (ROW)—A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes.

Roadway—The portion of a highway, including shoulders, for vehicular use.

Robotics—The science of dealing with robots (Isaac Asimov's definition). A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks. (From the Robot Institute of America.)

Sand—Granular, gritty, loose grains between 0.05 mm (0.002 in.) and 2 mm (0.079 in.) in diameter capable of passing a No. 4 sieve. Individual grains are readily seen and felt. No plasticity or cohesion. When dry, sand cannot be molded but will crumble when touched.

Silt—Fine, barely visible grains between 0.005 mm (0.0002 in.) and 0.05 mm (0.002 in.) in diameter capable of passing a No. 200 sieve. Little or no plasticity and no cohesion. A dried cast is easily crushed. More permeable than clays but pavement of water through the voids is difficult when dewatering. Silt is gritty and will not form a thread.

Site—The land area where a facility is located or activity is conducted, including any adjacent land used in connection with the facility or activity.

Sonde/Transmitter—A battery-operated, self-contained radio frequency transmitter housed immediately behind the drill bit. Used in the mini horizontal directional drilling (mini-HDD) operation for tracking the progress of the drillbit.

Specifications—A part of the contract documents, contained in the project manual, consisting of written requirements for materials, equipment, construction systems, standards, and workmanship. Usually includes the conditions of the contract.

Thrust Block—A structural reaction member that transmits a horizontal force from the pipe jacks to the ground. It is normally located at the rear of the shaft.

Torque—The measure of rotary force available at the drive chuck.

Trenchless Technology—Techniques for utility line installation, replacement, rehabilitation, inspection, location, and leak detection, which require no or minimum excavation and disruption.

Utility—A privately, publicly, or cooperatively owned line, facility, or system for producing, transmitting, or distributing communications, cable television, power, electricity, light, heat, gas, oil, crude products, water, and steam to the public A utility may process wastewater and disburse stormwater not connected with highway drainage and may include a fire or police signal system or street lighting system.

Water Table—The elevation to which groundwater would rise in an open bore hole.

Wing Cutters—Appendages on cutting heads that open to increase the cutting diameter of the head when turned in a forward (clockwise rotation) direction and close when turned in a reverse (counterclockwise rotation) direction.

APPENDIX A

Questionnaire Sent to State Transportation Agencies

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Project 20-5, Topic 27-01

Trenchless Construction of Conduits Beneath Roadways

QUESTIONNAIRE

Name of respondent: ____________________
Agency: ____________________
Title: ____________________
Phone No.: ____________________
Fax No.: ____________________

Note: For the purpose of this survey, *trenchless construction* is defined as all methods of installing below grade conduits without utilizing an open cut trench.

This project will focus on five (5) common trenchless methods used to install new conduits beneath roadways. These include: Microtunneling (MT), Auger Boring (AB), Pipe Ramming (PR), Horizontal Directional Drilling (HDD), and Mini-Horizontal Directional Drilling (Mini-HDD).

While these five (5) methods remain the focus of the study, the scope of this **research will include a search for other methods** that may be applicable for installing conduits under roadways.

For the purpose of the survey the definitions of these five methods is as follows:

Microtunneling: A remotely controlled, guided pipe jacking process that provides continuous support to the excavation face. The guidance system usually consists of a laser mounted in the jacking pit as a reference with a target mounted inside the microtunneling machine's articulated steering head. The microtunneling process does not require personnel entry into the tunnel. A key element of microtunneling is the ability to control the stability of the face by applying mechanical or fluid pressure to the face to balance the earth and groundwater pressures.

Auger Boring: A technique for forming a bore from a drive pit to reception pit by means of a rotating cutter head. Spoil is removed back to the driving shaft by helicaly wound auger flights rotating in a steel casing. The equipment may have limited steering capability but does not provide continuous support to the excavation face, a key distinction from microtunneling.

Pipe Ramming: A non-steerable system of forming a bore by driving an open-ended steel casing using a percussion hammer from a drive pit. The soil may be removed from the casing by auguring, jet-cutting, or compressed air. In appropriate ground conditions, a closed pipe may be used.

Horizontal Directional Drilling: Also called *Guided Boring* is a steerable system for installing pipes, conduits and cables in a shallow arc using a surface launched drilling rig. Traditionally the term applies to large scale crossings in which fluid filled pilot hole is drilled without rotating the drill string, and then enlarged by a back reamer to the desired size to accommodate the product pipe. The steering is provided by the positioning of the bent stub. Tracking of the drill stem is achieved by the use of a downhole survey tool.

Mini-Horizontal Directional Drilling: Also called *Guided Boring* is a surface-launched method for installing product pipes or utility lines up to 10 inches in diameter, in lengths of 600 feet or less, at depths typically less than 30-50 feet. Maximum thrust/pullback capacity is approximately 20,000 pounds and torque capacity less than or equal to 250 ft-lbs.

GENERAL INFORMATION:

1. When was the first time you became familiar with the possibilities presented by **trenchless construction** ? Year: ___________

2. Does your agency have any current projects involving installation of new conduits under roadways? ☐ Yes ☐ No

3. Totals of repairs/rehabilitation/new conduits undertaken:

in 1993__________ ft
in 1994__________ ft
in 1995__________ ft

4. For each year what is the approximate **cost** breakdown of the nature of work performed:
1993: _______ % repair _______ % rehab _______ % new
1994: _______ % repair _______ % rehab _______ % new
1995: _______ % repair _______ % rehab _______ % new

5. For each year estimate **cost** breakdown of work performed using conventional open cut and trenchless methods.
1993: _______ % Open-cut _______% Trenchless
1994: _______ % Open-cut _______% Trenchless
1995: _______ % Open-cut _______% Trenchless
Please explain what is the source of this information______________________________
____

6. Do your current specifications address:
(See cover sheet for definitions)

Comments

MT: Yes ☐ No ☐ _______________
AB: Yes ☐ No ☐ _______________
PR: Yes ☐ No ☐ _______________
HDD: Yes ☐ No ☐ _______________
Mini-HDD: Yes ☐ No ☐ _______________
Other: Yes ☐ No ☐ Describe:____________________

7. If you answered "Yes" to any question in (6) please indicate the year in which the trenchless method was first included in you current specifications.

MT: Year ________
AB: Year ________
PR: Year ________
HDD: Year ________
Mini-HDD: Year ________
Other: Year ________

8. Have you or any member of your staff ever attended training programs that address: MT, AB, PR, HDD, Mini-HDD, or other trenchless method ?

Yes ☐ No ☐

If "Yes", please explain the **nature and duration (hours)** of these training programs:

____

____

9. Do you think more training and education is necessary to help the design community make better decisions as to the use of open-cut Vs trenchless for a given project?

Yes ☐ No ☐

If "Yes", please explain what type of training you think would be most effective.

____

____

10. What do you think are the areas for future research in trenchless technology?

____

NCHRP Project 20-5, Topic 27-01
Agency: ____________________

DESIGN CRITERIA:

11. When conduits are being placed beneath roadways by methods other than open cut, what are your major concerns ? (Please rank into groups: **A** - highest concern, **B** - moderate concern, **C** - low concern)

Traffic Disruption	_____	Presence of other utilities	_____
Ground Settlement	_____	Presence of contaminated soils	_____
Ground Heaving	_____	Presence of subsurface obstacles	_____
Line and Grade Control	_____	Safety	_____
Vibration	_____		
Noise	_____		
Footprint of the Setup	_____	Other ________________	_____

12. Do your current specifications require **Casing Pipe** to be installed for placing conduits beneath roadways ? Yes ☐ No ☐

13. How many permits are issued each year by your agency for roadway/RR/etc. crossing?
Average number of permits each year __________

14. Do you provide inspection services for roadway/RR/etc. crossings ? Yes ☐ No ☐

15. What methods do you require to insure existing underground conduits are properly located prior to installing new conduits?

____

____

16. Has your agency experienced any major construction problems such as settlement or sink holes, associated with existing buried conduits ? Yes ☐ No ☐
If "Yes", please explain

____

____

17. What criteria, if any, do you have in pre-qualifying contractors, equipment and operators for trenchless work ?

Contractors:

____

Operators:

____

Equipment:

____

18. What do you think are the *real or perceived* limitations to open-cut trenching method when applied in installation of new conduits under roadways?

____

____

____

19. Are field logs prepared during installation? Yes ☐ No ☐
If "Yes" what information is recorded?

____

20. Are pre-construction tolerances provided? Yes ☐ No ☐
If "Yes" how are they enforced? ____

SELECTION CRITERIA:

21. Please make copies of the attached **Trenchless Project Description Forms** for providing information on trenchless projects involving installation conduits under roadways

Trenchless Project Description   Project Number ______________

1. Select one box that describes the trenchless method used on this project:
☐ Microtunneling ☐ Auger Boring ☐ Pipe Ramming ☐ HDD ☐ Mini-HDD
Select one box that describes where the new installation was undertaken for this project:
☐ under roadway ☐ under highway ☐ under railroad ☐ Other, Please explain ____________

2. Year in which project was completed __________

3. Cost of the project $ __________

4. Time to complete the installation _____ days _____ hours

5. Length of installed conduit _______ ft Size of installed conduit _______ in

6. Type of pipe installed ☐ Steel ☐ Concrete ☐ HDPE ☐ Other ________

7. Average depth of installed conduit ______ ft

8. Site conditions encountered ☐ Clay ☐ Sand ☐ Gravel ☐ Other ________
Average depth of water table ________ ft

9. Were alternate methods of installation investigated for this project? ☐ Yes ☐ No
If "yes", please explain what they were
____

10. Are you aware of any problems incurred during this project? ☐ Yes ☐ No
If "yes", please list the nature of the problems incurred.

☐ surface subsidence ☐ delay
☐ fluids migrating to surface ☐ unable to complete the job by chosen method
☐ other, please explain ______________________

Please explain briefly what action was taken to correct the problem:
____

APPENDIX B

Summary of Transportation Agency Practices

SUMMARY OF QUESTIONNAIRE RESPONSES

Trenchless Construction of Conduits Beneath Roadways

Agency	New[1] Conduits		Specifications/Year[2]						Greatest Concerns[3]						Trenchless Projects[4] *T/L/D/C/Y*
	OC %	*TC* %	*MT*	*AB*	*PR*	*HDD*	*MHDD*	*Other*	*TD*	*GM*	*LG*	*NV*	*PU*	*S*	
Alabama DOT	50	50	No	No	No	No	No			X			X	X	HDD/2000//1300/96 HDD/3400/70/875/96
Alaska DOT			No	No	No	No	No			X			X	X	
Alberta DOT, Canada	95	5	No	1982	No	No	No						X		AB/250/3/43/94
Arizona DOT	90	10	No	No	No	No	No		X	X			X	X	
Arkansas DOT	0	100	No	No	No	No	No			X			X	X	HDD/587/1.5/ /95 HDD/620/2.5/2.5/96 PJ/1617/3/325/95 PJ/950/3/558/93
CALTRANS	99	1	No	No	1972	No	No		X	X					
Conneticut DOT	100	0	No	No	No	No	No		X		X		X		
Delaware DOT	20	80	No	No	No	No	No			X			X	X	
Florida DOT			No	1970		1993	1993			X	X		X	X	
Georgia DOT	90	10	No	1988	1988	1988	1988		X	X			X	X	HDD/230/4/ /95 HDD/250/5/ /95

1 - New conduit installation reported for 1993-95. *OC = % Open Cut, TC = % Trenchless Construction*

2 - *MT = Microtunneling, AB = Auger Boring, PR = Pipe Ramming, HDD = Horizontal Directional Drilling, MHDD = Mini-Horizontal Directional Drilling, T = Tunneling, PJ = Pipe Jacking*

3 - *TD = Traffic Disruption, GM = Ground Movement, LG = Line & Grade Control, NV = Noise & Vibration, PU = Presence of Subsurface Utilities, Obstacles &/or Contaminated Soil, S = Safety*

4 - *T = Type of trenchless project, L = Length of conduit (ft), D = Average depth of conduit below ground surface (ft), C = Actual cost of installation in thousands (US $), Y = Year installed.*

SUMMARY OF QUESTIONNAIRE RESPONSES

Trenchless Construction of Conduits Beneath Roadways

Agency	New[1] Conduits		Specifications/Year[2]						Greatest Concerns[3]						Trenchless Projects[4] *T/L/D/C/Y*
	OC %	*TC* %	*MT*	*AB*	*PR*	*HDD*	*MHDD*	*Other*	*TD*	*GM*	*LG*	*NV*	*PU*	*S*	
Hawaii DOT			No	No	No	No	No		X				X		
Idaho DOT	80	20	No	1981	1993	1993		1975[5]	X	X					PR/4000/4/650/95 PR/2000/4/618/94
Indiana DOT			No	No	No	No	No		X	X			X	X	
Iowa DOT			No	No	No	No	No	1975[6]							PJ/1872/ /490/
Louisiana DOT	1	99	No	1988	1988	1988	1988		X	X			X		
Maryland DOT	10	90	No	1979	No	No	No		X	X	X		X	X	
Missouri DOT	70	30	No	No	No	No	No						X		
Montana DOT	99	1	No	No	No	No	No			X			X		
Nebraska DOT	93	7	No	1993	No	No	No						X		
New Jersey DOT			Yes	Yes	Yes	Yes	Yes			X	X	X	X	X	
New York DOT	95	5	No	No	1965	No	No	1990[5]			X		X	X	PJ/88/82/209/95
North Carolina DOT	99	1	No	1975	1975	No[7]	No[7]		X	X			X	X	

5 - *Tunnel liner for large diameter sanitary/storm sewers*
6 - *Pipe jacking*
7 - *Under review*

SUMMARY OF QUESTIONNAIRE RESPONSES

Trenchless Construction of Conduits Beneath Roadways

Agency	New[1] Conduits		Specifications/Year[2]						Greatest Concerns[3]						Trenchless Projects[4] *T/L/D/C/Y*
	OC %	*TC %*	*MT*	*AB*	*PR*	*HDD*	*MHDD*	*Other*	*TD*	*GM*	*LG*	*NV*	*PU*	*S*	
Ohio DOT	97	3	Yes	Yes	Yes	Yes	Yes		X	X			X	X	AB/155/10/38.5/96 AB/318/5/89/96 AB/50/5/19/96
Rhode Island DOT	100	0	No	No	No	No	No		X				X	X	
South Carolina DOT			No	No	No	No	No	8		X					
South Dakota DOT			No	1988	1969	No	No		X	X					
Tennessee DOT			No	No	No	No	No		X	X				X	
Texas DOT			No	1974	1974	No	No	9		X			X		
Virginia DOT	100	0		Yes	Yes				X	X			X		
West Virginia DOT			Yes	1972	1972	1972	1972				X		X	X	

8 - *No Wet Boring under highways/roadways*
9 - **Tunneling**

SUMMARY OF QUESTIONNAIRE RESPONSES

Trenchless Construction of Conduits Beneath Roadways

Agency	New[1] Conduits		Specifications/Year[2]						Greatest Concerns[3]						Trenchless Projects[4] *T/L/D/C/Y*
	OC %	*TC %*	*MT*	*AB*	*PR*	*HDD*	*MHDD*	*Other*	*TD*	*GM*	*LG*	*NV*	*PU*	*S*	
Manitoba DOT, Canada	96	4	No	1993	1993	No	No								
Nova Scotia DOT, Canada			No	No	No	No	No		X	X			X	X	
Prince Edward Island, Canada	0	100	No	1982	No	No	No		X	X				X	
Florida Power & Light Co.	50	50	No	No	No	1991	1991	9		X			X	X	
Georgia Power			No	No	No	No	1986						X	X	
Haworth, Meyer & Boleyn, W. Virginia	70	30	No	1980	1980	No	No		X	X			X		AB/80/6/13.5/95 AB/300/18/90/95
NYNEX	1	99	nO	1965	1965	1995	1994				X		X	X	HDD/2580/30/ / 95 MHDD/100/5 /95
Univ. of Alabama									X				X		

APPENDIX C

Related Organizations

American Society of Civil Engineers (ASCE)
1801 Alexander Bell Drive
Reston, Virgina 20191
Phone: 703–295–6000 Fax: 703–295–6222

American Underground-Construction Association (AUA)
511 11th Avenue South, Suite 248
Minneapolis, Minnesota 55415
Phone: 612–339–5403 Fax: 612–339–3207

Center for Advancement of Trenchless Technology (CATT)
University of Waterloo, 200 University Avenue West
Waterloo, Ontario N2L 3G1 Canada
Phone: 519–888–4770 Fax: 519–746–6556

Distribution Contractors Association (DCA)
Woodcreek Plaza
101 W. Renner Road, Suite 250
Dallas, Texas 75082–2003
Phone: 214–680–0261 Fax: 214–680–0461

Directional Crossing Contractors Association (DCCA)
One Galleria Tower, Suite 1940
13355 Noel Road, LB 39
Dallas, Texas 75240–6613
Phone: 214–386–9545 Fax: 214–386–9547

Electric Power Research Institute (EPRI)
3412 Hillview Avenue
Palo Alto, California 94304–1395
Phone: 415–855–2306 Fax: 415–855–2954

Equipment Manufacturers Institute (EMI)
10 South Riverside Plaza
Chicago, Illinois 60606–3710
Phone: 312–321–1470 Fax: 312–321–1480

Gas Research Institute (GRI)
8600 W. Bryn Mawr Avenue
Chicago, Illinois 60631
Phone: 312–399–8354 Fax: 312–399–8170

Gulf Coast Trenchless Association (GCTA)
P.O. Box 231333
Houston, Texas 77023

International Society for Trenchless Technology (ISTT)
15 Belgrave Square
London SW1X 8PS, UK
Phone: 44–71–259–6755 Fax: 44–71–235–6976

North American Society for Trenchless Technology (NASTT)
435 N. Michigan Avenue, Suite 1717
Chicago, Illinois 60611–4067
Phone: 312–644–0828 Fax: 312–644–8557

National Utility Contractors Association (NUCA)
4301 N. Fairfax Drive, Suite 360
Arlington, Virginia 22203
Phone: 703–358–9300

Trenchless Technology Center (TTC)
Louisiana Tech University
P.O. Box 10348
Ruston, Louisiana 71272
Phone: 318–257–4072 Fax: 318–257–2562