SCHOOL OF CIVIL ENGINEERING

FHWA/IN/JHRP-87/1-2

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

JHRP Project No. C-36-672
File No. 9-11-26

Executive Summary

CONSTRUCTION SPECIFICATIONS FOR HIGHWAY PROJECTS REQUIRING HORIZONTAL EARTH BORING and/or PIPE JACKING TECHNIQUES

Donn E. Hancher
Thomas D. White
D. Thomas Iseley

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

JHRP Project No. C-36-672
File No. 9-11-26

Executive Summary

CONSTRUCTION SPECIFICATIONS FOR HIGHWAY PROJECTS REQUIRING HORIZONTAL EARTH BORING and/or PIPE JACKING TECHNIQUES

Donn E. Hancher
Thomas D. White
D. Thomas Iseley

PURDUE UNIVERSITY

DIVISION OF CONSTRUCTION
ENGINEERING AND
MANAGEMENT

Executive Summary

CONSTRUCTION SPECIFICATIONS FOR HIGHWAY PROJECTS REQUIRING HORIZONTAL EARTH BORING and/or PIPE JACKING TECHNIQUES

TO: H. L. Michael, Director
Joint Highway Research Project

July 7, 1989

FROM: T. D. White, Research Engineer
Joint Highway Research Project

Project: C-36-672
File: 9-11-26

Attached is the Executive Summary of the Final Report for the above referenced project. The study was conducted and the report authored by Dr. D.T. Iseley, Graduate Research Assistant, under the direction of Professors T.D. White and D.E. Hancher.

The major objective of this study was to evaluate the various horizontal earth boring and pipe jacking techniques used by highway agencies for placing drainage structures and utilities under highways and railroads. Background information on all known methods, materials, and equipment are provided in the report. Current design procedures are reviewed and summarized. Recommended modifications to existing guidelines and specifications are presented.

This Final Report is forwarded for review and acceptance by all sponsors as fulfilling the objectives of the study.

Sincerely,

Thomas D. White
Research Engineer

CIVIL ENGINEERING BUILDING, ROOM 1223 • WEST LAFAYETTE, IN 47907 • (317) 494-2240

EXECUTIVE SUMMARY

CONSTRUCTION SPECIFICATIONS FOR HIGHWAY PROJECTS REQUIRING HORIZONTAL EARTH BORING and/or PIPE JACKING TECHNIQUES

Joint Highway Research Project
Project No. : C-36-672
File No. : 9-11-26

Conducted For :

Indiana Department of Highways

Prepared By :

D. E. Hancher, Research Engineer
T. D. White, Research Engineer
D. T. Iseley, Research Assistant

This research was carried out by the Joint Highway Research Project, Purdue University, under the direction of the first author as the principal investigator. The contents do not necessarily reflect the official views or policies of the Indiana Department of Highways.

PURDUE UNIVERSITY
School of Civil Engineering
West Lafayette, Indiana

July, 1989

EXECUTIVE SUMMARY

The formal objectives of this project as originally stated in the project proposal were as follows:

* Conduct an evaluation of all known methods of placing utilities beneath highways and railroads without trenching.
* Conduct an evaluation of materials commonly used with horizontal earth boring, pipe jacking and utility tunneling techniques.
* Review design practices and principles associated with trenchless excavation methods.
* Review specifications commonly used by other state highway departments and consulting engineers.
* Obtain maximum input from industry to identify weak areas associated with current specifications.
* Develop recommended guidelines and specifications for projects requiring horizontal earth boring, pipe jacking and utility tunneling techniques.
* Make recommended implementation procedures.

All proposed objectives were accomplished, and they are discussed in detail in the Final Report. This executive summary will briefly describe the methods evaluated and the items that should be included in the specifications.

Trenchless excavation construction (TEC) methods include all methods of installing utility systems below grade without direct installation into an open-cut trench. Figure 1 illustrates a classification system for TEC methods that was developed for this research project and is being adopted by industry. This system segments the industry into 3 major categories : (1) horizontal earth boring (HEB), (2) pipe jacking (PJ), and (3) utility tunneling (UT).

Horizontal earth boring (HEB) includes methods in which the borehole excavation is accomplished through mechanical means without workers being inside the borehole. Both PJ and UT TEC techniques require workers being inside the borehole during the excavation and casing installation process. However, PJ is differentiated from UT by the characteristics of the support structure. PJ methods utilize prefabricated pipe sections. New pipe sections are installed in the pit when the jacks are in a retracked position so that the complete string of pipe can be jacked forward. While UT techniques may use the same excavation equipment, the support structure is constructed at the face. Normally, this will be accomplished in the tail end of a tunneling shield. This support structure is normally traditional tunnel liner plates (TLP) or steel ribs with wood lagging (SRw/WL).

TEC methods have traditionally been associated with just alternatives to open-cutting for roadways, railroads, and other sensitive areas that cannot tolerate the disruption

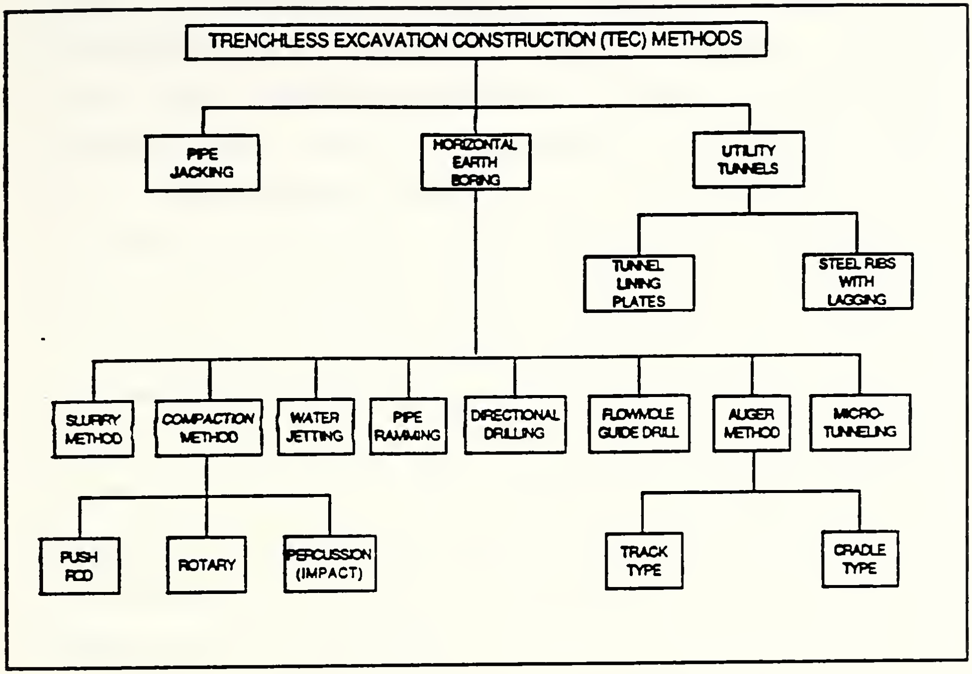

FIGURE 1. Trenchless Excavation Construction (TEC) Classification System

which results from open-cutting. As areas become more congested, TEC methods are being specified for the installation of complete utility systems. Thus, the smaller diameter sizes (i.e., diameters less than 42 inches) have received a disproportionate amount of research and development. This size range includes the majority of piping networks used for all the utility systems (i.e., water, petroleum products, sanitary and storm sewers) while the larger sizes are necessary for sanitary and storm sewer outfall systems.

Rapid development of new methods and significant innovations in traditional methods have resulted in considerable confusion with regard to a classification system and the principles and practices associated with these methods. Prior to conducting an evaluation of the methods a classification system had to be developed.

Figure 1 illustrates the classification system which is consistent with previous definitions. All methods associated with the horizontal earth boring category are differentiated by basic principles of operation. While no one method is best suited for all conditions, some do provide more flexibility than others. It is important that the installer, designer, and regulatory agencies involved with TEC methods be familiar with the capabilities of the available methods.

It was not the intent of this project to unjustifiably restrict the use of any method, but to describe the basic principles of operation so that methods permitted are compatible with conditions encountered.

Due to the increasing critical nature of installations of utility systems in congested areas, the need for monitoring and control systems have increased. In many situations, it is not acceptable for the alignment and grade to be left to chance. It has become necessary that such systems be installed with a high degree of accuracy. However, it is certainly recognized that conditions vary from project to project. Therefore, the methods permitted should be based on an evaluation of the specific project. Methods considered acceptable in stable clay may not be suitable in unstable wet sand, and the required accuracy for a sanitary gravity sewer line is not necessary, in most cases, for lines transporting water or petroleum products.

TEC methods are traditionally used at critical and sensitive locations during the installation of a system. Examples of such locations may be roadways, railroads, rivers, buildings, etc. Therefore, it is not reasonable for industry standard practice to permit methods that encompass too high of a degree of risk in the name of promoting competition and contractor flexibility.

At critical locations which involve public health and safety, it becomes the designer's and regulatory agency's responsibility to limit proposed methods to those only compatible for the conditions. This should be accomplished with adequate and complete specifications that can only be prepared with an understanding of the operating principles of available methods.

To assist in the process of developing an understanding of the various methods illustrated in Figure 1, each will be defined and described briefly:

AUGER HORIZONTAL EARTH BORING (HEB) : This method utilizes the process of simultaneously jacking casing through the earth while removing the spoil inside the encasement by means of a continuous rotating flight auger. The auger is a flighted drive tube having couplings at each end that transmits torque to the cutting head from the power source located in the bore pit and transfers spoil back to the machine. The auger HEB method is traditionally classified as: (1) track-type or (2) cradle-type. The major components of the track-type system include the track system, machine, casing pipe, cutting head, and augers. Since the cradle-type machine is supported by the trailing end of the casing pipe, the need for a track system is eliminated. However, hoisting equipment (i.e., cranes, pipelayers, excavators, etc.) will be required to support the casing pipe as the TEC proceeds. In addition to these major components, many optional components are available which include a bentonite lubrication system, a steerable (grade control) head, a casing leading edge band, a water internal injection system and a dutch water level indicator. Four major factors of concern include: (1) minimizing torque, (2) minimizing thrust, (3) leading end of casing location, and (4) being able to control the direction of the leading end of casing. The steerable (grade control) head and the dutch water level system are not applicable to the cradle-type methods.

COMPACTION HORIZONTAL EARTH BORING (HEB) : This method forms the borehole by means of compressing the earth that immediately surrounds the compacting device. The soil is not removed. It is displaced. Thus, this method is restricted to relatively small diameter lines (i.e., 2 inches to 6 inches) in compressible soil conditions. The compaction HEB method is divided into three sub-classifications which are: (1) push rod method, (2) rotary method, and (3) percussion (impact) method. These methods are commonly referred to as expansive installation techniques which mean the volume of the pipe installed exceeds the volume of the excavated soil; therefore, the earth surrounding the borehole will be displaced by the expanding effect. While these techniques have been in use for many years, they have been limited in their application due to their inherent unpredictable degree of accuracy. Typically, the degree of accuracy was a function of the soil characteristics and the presents of obstructions with the operator being unable to detect the location of the leading end of the boring device; and being unable to control its direction. However, within the last couple of years both location detection and steering systems have been developed by several manufacturers. These systems have been field tested and are being marketed. Their success has been extremely encouraging. This capability removes much risk and improves the allowable distance associated with TEC methods.

SLURRY HORIZONTAL ROTARY DRILLING METHOD (SRD) : This method is distinguished from horizontal auger boring in that it utilizes drill bits and drill tubing in lieu of augers and cutting heads. A drilling fluid, such as: a bentonite slurry, water, or air, is used to facilitate the drilling process by keeping the bit clean and aiding in spoil removal. Because of this latter characteristic, it is often confused with the jetting method; however, unlike the jetting method, the SRD method does not use the drill fluid to cut the face or to wash out a hole. The face is cut mechanically by the bit. Wash-outs are prevented by controlling the drill fluid rate of flow and pressure. SDR offers the distinct advantage of being able to install a small diameter pilot hole before the main bore is developed. This insures line and grade accuracy. Should obstructions be encountered, their nature and alternatives can be evaluated with minimum cost and risk. Various techniques can be utilized to adapt the SRD method to be compatible with unstable soil conditions. The SRD method is primarily suited for the smaller diameter sizes (i.e., 2 inches to 6 inches); however, larger sizes are commonly installed where soil conditions permit. The recommended bore length is a function of soil conditions; however, the length should be limited to approximately 40 feet unless drill bit location and directional control systems are utilized.

WATER JETTING METHOD : This method utilizes the liquefaction of soil principle to create a borehole. Water pressure and flow rate create a jetting action which places the soil in a quick (liquid) condition for the purpose of eroding the borehole. Water jetting requires minimum equipment investment. The necessary equipment includes a source of pressurized water, a flexible hose, probe, and nozzel. A flexible hose transmits water from the source to the probe. The probe is usually a rigid small diameter pipe that is used to direct the water as it cuts or washes out a borehole. The nozzel increases water velocity which aids in the jetting process. The length of the bore is controlled by adding extensions on to the probe rod. While this method is simple and economical, the long term effects have been adverse; thus, the method has been banned in all areas with the exception of owners using it in isolated areas. It lacks directional control and is associated with significant subsidence problems.

PIPE RAMMING METHOD : This method is an innovative use of the percussion tool. The percussion (impact) technique is one of the three basic compaction methods previously described. However, with the compaction method the impact tool is utilized to actually create the borehole; and with the pipe ramming method, the impact tool is used as the driving hammer to force direct pipe burial. The two basic methods are closed face or open face. The closed face utilizes the soil expansion principle as the soil is not removed; therefore, the pipe volume exceeds the volume of soil displaced. However, the open face technique uses the same equipment and methods; but soil is removed from within the pipe. There are several satisfactory techniques that are commonly used to remove the spoil from inside the pipe. Bentonite has been used successfully to reduce skin friction. Accuracy is a function of soil conditions and the presents of obstructions. Directional control is limited to the degree of accuracy taken during the initial set up. Casing leading edge detection systems have been used with success, but they are not commonly used.

DIRECTIONAL DRILLING METHOD : This method of crossing natural or manmade obstacles is an outgrowth of technology and methods developed for the directional drilling of oil wells. It was developed in the United States, and has revolutionized complicated pipeline river crossings. It is currently recognized as a viable method for certain roadway/ railroad crossings. The two stage directional drilling process consists of: (1) drilling a small diameter pilot hole along the desired centerline of the proposed pipeline, (2) enlarging the pilot hole to the desired diameter to accommodate the pipeline. The pilot hole is drilled with a specially built drill rig that allows the drill string to enter the ground at an angle of entry which can vary from 5 to 30 degrees; however, the optimum entry angle is 12 degrees. The drill rig forces the drill stem into the ground, and bentonite drilling mud is pumped through the drill stem to a down hole motor located behind the bit. The drill mud operates the down hole motor, functions as a coolant, and facilitates spoil removal by washing the cuttings to the surface where they settle out in a retention pit. The drill stem is approximately 3 inches in diameter, nonrotating, and contains a slightly bent section which is called a bent housing. The bent housing (typically from 0.5 to 1.5 degrees) is used to create a steering bias. A curved or a straight profile is achieved by steering the drill rod as it is being pushed into the ground. The steering is controlled by the positioning of the bent housing. The pilot hole path is monitored by a down hole survey system located behind the bent housing and provides data on the inclination, orientation, and azimuth of the leading end. This data is transmitted to the surface where it is interpreted and plotted. Normally, position readings are taken on every pipe segment which is about every 30 feet. Should the pilot hole get out of alignment, then the drill stem is pulled back and a new course is cut. During the drilling operation, a 5 inch diameter steel washover pipe is rotated over the pilot drill stem. The washover pipe relieves the friction and resisting pressure caused by the cuttings mixed with the drill mud. In addition, the washover pipe provides rigidity to the pilot drill stem. Bentonite slurry is pumped between the washover pipe and the pilot drill stem. The rotation of the washover pipe allows the diameter of the borehole to be increased to approximately 11 inches. After the pilot hole has been constructed then the pilot drill stem is withdrawn through the washover pipe. Reaming devices are attached to the washover pipe, and pulled back through the pilot hole enlarging it to the desired diameter suitable to accept the designed pipeline.

FLOWMOLE GUIDEDRILL METHOD : This method is a proprietary system developed and operated by FlowMole Corporation, Kent, Washington which offers a unique steering capability for small diameter systems installed at depths that extend to 15 feet and lengths that extend to 600 feet. The patented SoftBor process is characterized as a low flow (1 to 2 GPM) with high pressure (1,000 to 4,000 PSI) soil cutting system. While a bentonite slurry performs the cutting action, it is differentiated from the water jetting and the slurry rotary drill method as previously described due to the pressures and flowrates that actually create the cutting action. Soil erosion and over cutting do not occur with the FlowMole system because the small diameter jets that produce the type of flow required are designed so that the cutting fluid's energy is dissipated rapidly. This prevents the cutting fluid from being able to cut through existing utility lines. Remote steering is accomplished through directing the cutting at the nose of the bore tool. The tool can be made to change directions as it is thrust through the ground. A computerized electronic control system provides steering commands for guiding the tool through the ground. The position of the tool can be determined within 1 inch both laterally and vertically.

MICRO-TUNNELING METHOD : These methods of horizontal earth boring are highly sophisticated, laser guided, remotely controlled with the capability of accurate monitoring and adjusting of the alignment and grade. This classification system applies to sizes which are equal to or less than 36 inches which means they are too small for workers to work inside efficiently. While it is true that these machines are manufactured to install sizes much greater than 36 inch, the term micro-tunneling is not appropriate. The larger machines would be suitable for the pipe jacking systems to be discussed later. Micro-tunneling machines are a fairly recent development; however, due to their unique capability of being able to install gravity sewer lines with extreme accuracy, the growth has been exponential. Their popularity has been much greater in other countries outside the United States; however, their use in the U.S. has expanded rapidly. There are over 30 manufacturers of micro-tunneling equipment worldwide with only one in the United States. The most widely used machines in the U.S. are the Japanese Iseki Poly-Tech, Inc.'s system, the German Dr. Soltau's system, and the American Augers, Inc.'s system. Iseki Poly-Tech, Inc. manufactures a wide variety of long distance pipe jacking and tunneling systems. These systems possess the state-of-the-art in technology to install small diameter pipelines in soft, unstable, water bearing soils. This is accomplished automatically and continuously by the mechanical earth pressure counter-balance (M.E.P.C.B.) system which coordinates excavation speed, cutting face pressure, and thrust force. This permits operation in water saturated sands, silts, clays, and gravels without dewatering or compressed air. This system utilizes a slurry pumping system to transport the excavated material from cutting face to the disposal process. All systems are electronically monitored and controlled from a single operation panel. The Soltau machines are similar in principle to the Iseki machines. They are sophisticated, automatic, micro-tunneling machines that can be continuously monitored and adjusted to provide the high degree of accuracy required for critical alignment and grade control necessary for the installation of sanitary and storm sewer systems. The major difference between these two systems are in the spoil removal systems. With the Soltau system, a bentonite slurry is injected at the cutting head, and the excavated material is removed in a slurry solution by means of augers located inside a casing to a holding tank which is located beneath the machine in the bore pit. The American Augers, Inc. system is laser guided with articulated steering and remote control. It is an innovative adaptation of the standard 36 inch horizontal earth boring machine.

PIPE JACKING (PJ) is segmented from horizontal earth boring by requiring the necessity of men working inside the pipe. While HEB techniques can be utilized on pipes as large as 60 inch, the excavation and spoil removal are completely mechanical. With PJ, the excavation process varies from the very basic manual process to the highly sophisticated tunneling boring machines (TBM). However, regardless of the excavation method, it is normally conducted inside a shield. The shield is designed to provide maximum worker safety. It is common practice within the industry to provide articulated shields that are guidable with individually controlled hydraulic steering jacks. The most common type of jacking material is reinforced concrete pipe and steel pipe.

UTILITY TUNNELING (UT) is differentiated from the major tunneling industry by virtue of their size and use. Utility tunnels are used primarily for conduits for utilities rather than as passageways for pedestrian and/or vehicular traffic. Further, while the excavation methods for UT and PJ may be identical, the differentiation is in the lining systems. With PJ, prefabricated pipe is the lining system; but with UT, the lining system is constructed in the tunnel. The most popular lining systems are steel tunnel liner plates, steel ribs and wood lagging, and wood box tunneling.

The extensive evaluation of the methods previously described resulted in the conclusion that the project specifications must be developed to address the specific project for which it is being utilized. A large number of field problems occur as a result of faulty, inaccurate, and incomplete specifications. Incomplete specifications require inspectors to apply judgment in areas for which they may have no experience.

This projects recommends that TEC projects should be segmented into at least three categories according to their degree of difficulty. The degree of difficulty should be a function of desired length, depth, size, groundwater conditions, soil conditions, surface and subsurface congestion, required accuracy, casing/carrier pipe, etc. Methods permitted would be a function of the category selected for the project.

The topics that should be considered for each TEC project are:

* Submittal information that should be submitted by the design engineer and contractor prior to work being executed.
* Requirements for subsurface investigations.
* Requirements for groundwater control.
* Requirements for access pits and vertical shafts.
* Requirements for materials.
* Accuracy requirements.
* Horizontal earth boring requirements.
* Pipe jacking requirements.
* Utility tunneling requirements.
* Ventilation requirements.

* Lighting requirements.
* Grouting requirements.
* Casing/carrier void filler requirements.
* Bulkhead requirements.
* Obstruction/changed conditions requirements.
* Abandonment requirements.
* Requirements for measurement.
* Requirement for payment.

The recommended guidelines and specifications developed as a result of this project should be incorporated into the Indiana Department of Highways Standard Specifications. However, it is important to realize that simply modifying specifications will accomplish little without proper training and educational programs for designers, permit reviewers, and inspectors.

During the duration of this research project, three seminars were conducted in Indianapolis for IDOH personnel. It was determined that the level of awareness and understanding concerning these methods was minimal among those with the responsibility to ensure the work is being executed properly. A statewide certification program should be developed.

COVER DESIGN BY ALDO GIORGINI