ASCE Manuals and Reports on Engineering Practice No. 106

Horizontal Auger Boring Projects

ASCE

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Prepared by the
Center for Underground Infrastructure Research and Education (CUIRE),
Michigan State University

Under direction of the
Horizontal Auger Boring Task Force of the
Committee on Trenchless Installation of Pipelines (TIPS)
Pipeline Division
American Society of Civil Engineers

Task Committee Chairman
Mohammad Najafi

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MANUALS AND REPORTS ON ENGINEERING PRACTICE

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PREFACE

This manual of practice (MOP) was prepared by the Center for Underground Infrastructure Research and Education (CUIRE) at Michigan State University, under direction of the American Society of Civil Engineers (ASCE), Pipeline Division, Trenchless Installation of Pipelines (TIPS) Committee, Task Committee on Horizontal Auger Boring Projects. As the name of the document implies, this manual describes current practices that engineers and construction professionals use to design and construct pipelines under roads, railroads, streets, and other man-made and natural structures and obstacles. The TIPS Committee, under leadership of Dr. Ahmad Habibian, PE, is credited for the efforts leading to this publication. Mr. Leo Barbera was instrumental in leading the preparation of this manual by contributing his knowledge from many years of experience in horizontal auger boring. The committee would like to thank all of the task committee members and reviewers, whose names follow, for their support, time, and efforts. Special thanks go to all of the sponsors of this manual, including Dr. Robert von Bernuth, Director of School of Planning, Design and Construction at Michigan State University, for providing the resources and support for preparation of this manual. The efforts of Mr. Guru Kulandaivel, CUIRE Research Associate, who spent many long hours coordinating the review process and writing the manuscript, are greatly appreciated.

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Under direction of the
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Part 1
GENERAL

1.1 INTRODUCTION AND BACKGROUND

Horizontal auger boring is a well-established trenchless method that is widely used for the installation of steel pipes and casings, especially under railways and road embankments. This economical trenchless pipe installation method can be used under various soil conditions, and it can be used advantageously to reduce pavement damage, traffic disruptions, and the social costs associated with pipeline installations.

There are, however, limits to the use of horizontal auger boring, and various conditions provide challenges to the procedure's success. This manual provides information that is essential to the contractor and the engineer for the successful and safe execution of horizontal auger boring procedures.

Although horizontal auger boring is the most widely used trenchless method for the installation of steel pipes and casings, especially under railways and road embankments, it has not been covered adequately by manuals, guidelines, or standards. The need to develop a comprehensive manual of practice for horizontal auger boring projects arose as a result of steady advancements in the field and the lack of proper guidelines. This manual of practice, developed by the Horizontal Auger Boring Task Force of the American Society of Civil Engineers (ASCE) Committee on Trenchless Installation of Pipelines (TIPS), is a major step toward promoting best practices and creating a knowledge base for horizontal auger boring projects.

This manual of practice has been prepared to assist engineers, contractors, and owners who are using the horizontal auger boring method to design and execute pipe installation projects effectively, safely, and in conformance with project requirements and site conditions. The objective of this manual is to give a clear understanding of the method's capabilities and limitations, to outline important design and construction considerations, and to identify potential problems and prevention measures, thereby instilling confidence in the appropriate use of the method.

These guidelines are based on information obtained from manufacturers' literature, technical papers, and other related information and from comments and reviews made by industry experts.

Horizontal auger boring is a technique for forming a bore from a drive pit by means of a rotating cutting head. Spoil is removed back to the drive pit by helical auger flights rotating in a steel casing. The basic components of a horizontal auger boring system include the base unit, casing pusher, power pack, auger sections, track, and track extensions. Cutting bits are available for different soil conditions.

1.2 HISTORY

Primarily used for road crossings, the horizontal auger boring method is a trenchless excavation technique used extensively throughout every segment of the United States. Although this method has evolved over the past 45 years, the major developments have taken place over the past 10 to 15 years and have resulted in increased bore lengths and accuracy.

Like most other construction equipment, horizontal auger boring machines were developed because of a contractor's need. As early as 1936, the first boring machines were made from rears of old trucks. These machines, built by CRC-Evans Pipeline International, were cradle auger boring machines in which the whole system is suspended by pipe-laying equipment.

The horizontal auger boring method was formally developed in the late 1940s by Vin Carthy, Salem Tool Company, and Charlie Kandal. The developments were simultaneous and independent of each other. Machines were originally developed to drill horizontal blast holes into open-cast coal mines that contained a thick seam of high-grade coal in Somerset, Pennsylvania. The seam was covered with fireclay and a deep layer of sandstone beneath the soil overburden. Because the coal became contaminated as a result of the disturbance caused by blasts, the use of explosives was not effective. These machines were used for boring from the working face along the bottom of the fireclay stratum and skimming the top of coal.

In the 1940s, Charlie Kandal founded the Kandal Motors (Ka-Mo) company, which manufactured the Ka-Mo horizontal auger boring machines. The initial machines were electrically operated, but later ones were gasoline powered. The shape and size of the machine required a deep pit for making a bore. These were large machines with a drop transmission having three speeds with one-speed reverse. Ka-Mo machines were designed to run on a track. The machines consisted of electric or air motors on a track with a series of holes. A bar called a *hand croud* was used to pry the machine forward. At that time, the bores normally were not cased, and the auger had a tendency to screw itself into the ground. Hence, there was no problem in prying it forward. In fact, in most instances the machine had to be held back to prevent it from screwing itself in the ground. Larger machines with approximately 16 horsepower (11,936 watts) air motors were equipped with two bars. By 1951, Ka-Mo claimed the capability to bore 5-in. (125 mm) diameter uncased holes up to 230 ft (70 m).

Both Salem and Ka-Mo dominated the horizontal auger boring business until 1961, when pipeline welder Al Richmond started manufacturing small horizontal auger boring machines. Richmond was working for Wert & Starn Pipeline Company, who was building boring machines under the trade name of Tornado. The Tornado was built with the engine on top of the gearbox and was driven with a chain. It had metal plates and slid in a track or on the ground. As with CRC-Evans machines, the process required a deadman in the ground in front of the boring machine.

Richmond built his own machines similar to those of Ka-Mo. His machines ran on a track and were equipped with a hand croud. The track was built with holes in the cross-members, and T-pins were used to hold it in the ground. He later changed the configuration of the machines and built bigger machines with hydraulic cylinders. His were the first centerline drive machines with the engine, transmission, gearbox, and hydraulic motor in one straight line with an automotive-type clutch instead of an over-center clutch. Richmond's main competition at that time was Ka-Mo, and Ka-Mo was still building large machines for small-sized installations. Ka-Mo was also spending a fortune building its own transmissions and gearboxes, while Richmond was using standard, off-the-shelf items that were much cheaper and easier to replace. Richmond's small units were very convenient and quickly became popular. Richmond's 24-in. (600 mm) machine, the *Power Midget*, was very popular; a lot of pipe was installed using these machines. Richmond also built 30-in. and 36-in. (750 mm and 900 mm) machines for bigger-diameter installations.

Because a significant amount of free boring was being done at that time, all machines had one hydraulic cylinder under them. As the technology advanced into cased bores, the thrust requirements increased, and Richmond used two cylinders under the machines. However, these machines were still being built on top of a track. Richmond later modified the design so that the machines were in the track, and later, he reluctantly split the machines for ease of handling. Richmond machines used Ka-Mo augers and cutting heads until 1967, when he built his own auger and cutting heads, which were exactly the same as those of Ka-Mo. Richmond was the only company to make advances in the equipment design to keep pace with the changing market.

Roy Woodruff and Son designed the split machine. They also put a spacer in a 36-in. (900 mm) machine to make it a 48-in. (1200 mm) machine. Ernie Coppica of Wixom, Michigan, invented the steering systems in the 1960s, and improvements in the cutting heads were made in the late 1960s.

In 1970, Leo Barbera left Richmond Manufacturing and founded American Augers. American Augers started by building hydrostatic drive machines with a built-in slip clutch. If the machine hit a boulder or some other obstruction, it would switch to maximum torque, but at the same time would block out the thrust. The machine would advance only when the condition was relieved. American Augers also developed the bores head method in the early 1970s.

The main developments in the 1980s were improvements in safety, education, and training. National Utility Contractors Association (NUCA) Horizontal Boring and Pipe Jacking Committee was formed in the 1980s, and the first manual on pipe jacking was published.

The other manufacturers of horizontal auger boring machines include McLaughlin Boring Systems, Horizontal Equipment Manufacturing Inc., Michael Byrnes Manufacturing, Bor-It Manufacturing, Barbco, and several other manufacturing firms. There are several contractors who manufacture their own boring equipment.

1.3 RECENT INNOVATIONS IN MECHANICAL AND ELECTRONIC LINE-AND-GRADE SYSTEMS

The most important innovations in recent years have been in the following areas:

1.3.1 Guided Boring Method

The guided boring method (GBM), also known as the pilot tube method, is used in conjunction with the horizontal auger boring machine to install small-diameter pipes with greater grade and alignment precision. The GBM consists of a specially designed theodolite guidance system to guide the installation of pipes. Accurate pipeline installation is achieved through video monitor surveillance of an illuminated target via theodolite. Pilot head steering is accomplished by aligning an angled pilot head for the desired course and thrusting forward. Pilot tubes are installed behind the steering head and rotated while simultaneously thrusting forward. After the steering head has reached the reception shaft, a reaming head and auger tubes with flighting are installed behind the pilot tubes. With the addition of each section of the auger tube in the launch shaft, a section of pilot tube is removed in the reception shaft. The process is repeated until all pilot sections have been removed. A pipe adapter is then installed on the last section of auger casing, and subsequent pipes are thrust into place while the auger tubes are removed from the reception shaft. The success of this method depends on the ground condition. This method is not recommended for soils with boulders because they could deflect the pilot tubes.

1.3.2 Controlled Boring System

The controlled boring system (CBS) is a steering system that controls line and grade for steel casing bores up to 48 in. (1,200 mm) in diameter. CBS uses a steering system that utilizes a walkover transmitter-locating system that monitors line and grade throughout the length of the bore. The boring machine operator can view any deflections throughout the bore path and make proper steering adjustments with an electric-over-hydraulic, push-button-controlled steering system with digital readout. The CBS can be used with most boring machines.

1.3.3 Development of New Steel Pipe Interlocking Joining System

The interlocking steel pipe joining system provides a preinstalled precision joint connection that provides quick, easy, and permanent joints. This joining system practically eliminates the need for in-field welding and associated downtime, thereby increasing productivity.

1.3.4 Laser-Guided Tunnel Attachment

A laser guidance system is used with the tunnel attachment to enhance the line and grade capability of horizontal auger boring machines and to accommodate larger-diameter pipes and greater lengths. See Section 3.4.2.4.

1.3.5 Mechanical Line and Grade Control Head

The mechanical line and grade control head is used for making minor corrections on both line and grade. See Section 3.4.2.1.

1.3.6 Electronic (Inertial) Line and Grade Control Head

The electronic line and grade control head technology permits increased accuracy in the installation of pipes using the horizontal auger boring method under appropriate site conditions. See Section 3.4.2.2.

1.4 SCOPE

This manual of practice presents facts on horizontal auger boring technology, supplemented by an analysis of limitations and applications of these facts. Part 2 of this manual presents the planning phase, Part 3 of this manual presents the design and preconstruction phase, Part 4 of this manual presents the construction phase, and Part 5 presents the list of references.

1.5 RELATED DOCUMENTS

American Society of Civil Engineers. 1997. *Geotechnical Baseline Reports for Underground Construction*. Reston, Va.: ASCE.

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American Society of Civil Engineers. 2002. *Standard Guidelines for the Collection and Depiction of Utility Data, Standard CI/ASCE 38-02*. Reston, Va.: ASCE.

Iseley, D. T., Najafi, M., and R. Tanwani. 1999. Trenchless Construction Methods and Soil Compatibility Manual. 3rd ed. Arlington, Va.: The National Utility Contractors Association.

Iseley, D. T., and S. B. Gokhale. 1997. *Synthesis of Highway Practice 242: Trenchless Installations of Conduits Beneath Roadways*. Washington, DC: Transportation Research Board, National Research Council.

1.6 GLOSSARY AND DEFINITIONS

Advance: The motion of the boring machine in a direction toward the face wall of the entrance pit.

Auger: A flighted drive tube with hex couplings at each end to transmit torque to the cutting head and transfer spoil back to the machine.

Auger Boring (AB): See **Horizontal Auger Boring (HAB).**

Auger Drive: See **Drive Chuck.**

Auger Machine: A machine used to drill earth horizontally by means of a cutting head and auger or other functionally similar device. The machine may be either cradle or track type.

Annular Space: The space between the borehole and the installed casing pipe or the space between the casing and the carrier pipe.

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

Backstop: The reinforced area of the entrance pit wall directly behind the track.

Band: A ring of steel welded at or near the front end of the lead section of casing to cut relief and strengthen the casing.

Bedrock: A general term for the rock, usually solid, that underlies soil or other unconsolidated bed material.

Bentonite: A colloidal clay sold under various trade names that forms a slick slurry or gel when water is added. See **Lubrication Fluid.**

Bits: Replaceable cutting tools on the cutting head or auger.
Bore: A generally horizontal hole produced underground primarily for the purpose of installing services.
Boring: The dislodging or displacement of spoil by a rotating auger or drill string to produce a hole called a bore.
Boring Machine: A machine to bore earth.
Boring Pit: See **Entrance Pit.**
Carriage: The mechanical part of a non-split boring machine that includes the engine or drive motor, the drive train, the thrust block, and hydraulic cylinders.
Carrier Pipe: The tube that carries the product being transported and that may go through casings at highway and railroad crossings. It may be made of steel, concrete, clay, fiberglass-reinforced polyester, plastic, ductile iron, or other materials. On occasions, it may be bored directly under highways and railroads.
Cased Bore: A bore in which a pipe, usually a steel sleeve, is inserted simultaneously with the boring operation. Associated mainly with horizontal auger boring.
Casing Adapter: A circular mechanism to provide axial and lateral support of a casing whose diameter is smaller than that of the casing pusher.
Casing Attachment: See **Casing Adapter.**
Casing Pipe: A pipe installed as external protection for a product pipe or carrier pipe.
Casing Pusher: The front section of a boring machine that distributes the thrusting force of the hydraulic cylinders to the casing and forms the outside of the spoil ejector system.
Centerline: The vertical distance between the center of the drive chuck and the ground plane (bottom of the track).
Chippers: See **Bits.**
Cleaning: An action of a boring machine to remove spoil that occurs when the auger is rotating while axially stationary.
Clutch: A mechanical device that engages or disengages rotary torque from a power source.
Collaring: The initial entry of casing or a cutting head into the earth.
Conduit: A broad term that can include pipe, casing, tunnels, ducts, or channels. The term is so broad that it should not be used as a technical term in boring or tunneling.
Control Lever: A handle that activates or deactivates a boring machine function.
Cradle Machine: A boring machine typically carried by another machine that uses winches to advance the casing.
Cross Members: The lateral supports under the track of a boring machine.

Cutter Head or Cutting Head: The actual teeth and supporting structure that is attached to the front of the lead auger. It is used to reduce the material that is being bored to sand or loose dirt so that it can be conveyed out of the hole.

Deadman: A fixed anchor point used in advancing a saddle- or cradle-type boring machine.

Deck Assembly: Drive-train assembly for a split-design boring machine.

Dewater: Any method used to lower the water table in the vicinity of the bore.

Dog Plate: See **Thrust Block.**

Dogs: Moveable protrusions in the thrust block that engage holes or blocks in the track.

Drive Chuck: The female hex connector located within the casing pusher.

Drive Shaft/Pit: See **Entrance Pit.**

Duct: In many instances, a term interchangeable with pipe. In the boring industry, it is usually used for small plastic or steel pipes that enclose wires or cables for electrical or communication usage.

Emergency Controls: Controls that stop power to machine or components.

Emergency Stop: A red, manually operated push button that, when activated, stops all functions of the machine.

Entrance Pit: An opening in the earth of specified length and width for placing the machine on line and grade.

Entry/Exit Angle: In any boring system, the angle to the ground surface at which the casing enters or exits in forming the bore.

Exit Pit: An opening located at the exit of the cutter head or casing.

Extension Track: An additional section of track used in front of the master track.

Face: Wall of the entrance pit into which the bore is made.

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

Forward Rotation: The clockwise rotation of the auger as viewed from the machine end.

Grade: The specified rise or fall of the proposed bore from a horizontal plane. Calculated as: (Rise/Run x 100%).

Ground Plane: The surface upon which the machine is placed.

Grout: A material used to fill the annular space around a casing or to seal a well or boring. The most common types of grout are neat cement grout, concrete grout, cellular grout, bentonite grout, and high-solid bentonite grout.

Guard: A protective device fitted to the machine to minimize the possibility of inadvertent contact with hazards.

Guided Auger Boring: The term applied to auger boring systems that are similar to microtunneling, but have the guidance mechanism actuator sited in the driveshaft. This pipe installation method uses pilot tubes and a theodolite to install small-diameter pipes with high accuracy.

Horizontal Auger Boring (HAB): A technique for forming a bore from a drive pit to a reception pit by a rotating cutting head. Spoil is removed back to the driveshaft by helically wound auger flights rotating in a steel casing. See **Guided Auger Boring.**

Helicoid: A continuous section of auger flighting.

Hold Down: A hinged or removable assembly that secures the boring machine to the track.

Hook Rollers: See **Hold Down.**

Laser-Guided Tunnel Attachment: A modified method of horizontal auger boring for 48 in. or larger that uses laser for guidance, capable of line and grade installations.

Line: The specified direction of the proposed bore in a horizontal plane.

Locator: The electronic instrument used to determine the position and strength of electromagnetic signals emitted from a transmitter in the pilot head of a boring system, in an impact moling tool, or from existing services that have been energized.

Lubrication Fluid: A mixture of water and/or bentonite pumped to a point just behind the cutting head to stabilize the borehole and provide lubrication for the casing, thereby reducing jacking forces.

Master Track: The rearmost track section.

Mixed Face: A soil condition that presents two or more different types of material in the path of the bore.

Open Cut: The conventional method of digging a trench for pipeline installations.

Piling: Rigid supports driven vertically to provide wall support in the pit.

Pilot Bore: The action of creating the first pass of any boring process that later requires enlarging.

Pipe Jacking: A system of directly installing pipes behind a shield machine by hydraulic jacking from a driveshaft, such that the pipes form a continuous string in the ground. Usually, personnel are required inside the pipe to perform the excavation or spoil removal process. The excavation can be performed manually or mechanically.

Pipe Pusher: A machine that pushes or pulls a rod or pipe to produce a bore by means of compaction without rotation or impact.

Power Package: The engine and drive section of a split boring machine or the remote engine and hydraulic pumps of a power unit.

Receiving Pit/Shaft: See **Exit Pit.**

Retract: The motion of the machine away from the face of the entrance pit.

Restoration: The backfilling, compaction, and resurfacing of any excavation in order to restore the surface and underlying structures, enabling it to perform its original functions.

Reverse: The counterclockwise rotation of the auger as viewed from the machine end.

Saddle: A vertical support mechanism to hold the casing in position while starting (collaring) the bore.

Saddle Adapter: An attachment that fits on the saddle to support smaller casings.

Safety Shield: A guard that, alone or with other parts of the machine, provides safety protection from the moving parts or heat of the machine.

Safety Sign: A notice attached to the machine that advises the nature and severity of potential hazards. It can also provide instructions to reduce or eliminate the hazard.

Sealing: A process of filling a well or boring with grout.

Shank: A hardened male hex bar containing one or more transverse holes to couple and hold in a female hex connector.

Sheet Piling: See **Piling.**

Shoring: See **Piling.**

Slick Bore: A bore made with casings. The product line is welded to casing and pushed into the bore, removing the casing.

Skin Friction: Resistance to thrust caused by earth pressure around the casing.

Split Design: A design enabling a boring machine to be broken down into two or more sections to reduce the lifting weight.

Spoil (Muck): Earth, rock, and other materials displaced by a tunnel or casing and removed as the tunnel or casing is installed.

Spoil Ejector: A set of paddles rotating in close proximity to the inside of the casing pusher.

Spoil Ejector Door: A safety guard that partially or completely covers the spoil opening in the casing pusher.

Steering Head: A moveable lead section of casing that can be adjusted to steer the bore.

Test Bore: Probing by auger or coring tool, usually vertically, at the site to determine soil conditions.

Thrust: The force that causes the boring machine to advance.

Thrust Bearing: An external bearing used to isolate the final drive from the thrusting force of the machine.

Thrust Block: A manually or remotely operated locking mechanism that engages stations in the track to provide a thrusting base for the machine advance and retraction.

Thrust Package: The section of a split boring machine containing the cylinders and thrust block.

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

Torque Plate: Steel plates welded to a casing and bolted to the casing adapter to prevent the casing from slipping.

Torque Windup: The energy stored when metal parts are held in a twisted condition. Release of this energy can cause unexpected rotation of the auger.

Torque Limiter: A rotary slip clutch used to protect the final drive.

Track: A set of longitudinal rails mounted on cross members that support and guide a boring machine.

Track Brake: A mechanical device to provide limited resistance to movement between the machine and the track.

Track Pins: Steel pins to be driven through holes in the track into the base of the pit to hold the track in place.

Transmission: A gear reduction unit located between the power source and final drive.

Trench Box: A pre-constructed set of side plates and adjustable cross members to prevent the walls of the pit from collapsing.

Upset: The inadvertent action of a boring machine that rotates the machine and track from its normal upright position to another position.

Underground Utility: Active or inactive service or utility already in the ground in the area of the proposed bore.

Wale, Waler: A bracing that supports the sheathing in an excavation.

Water Level: An instrument that uses a tube filled with water to indicate the elevation of the lead section of casing.

Water Table: The elevation of the groundwater.

Wing Cutters: Appendages on cutting heads that will open to increase the cutting diameter of the head when turned in a forward direction and will close when turned in a reverse direction. They are used to cut clearance for the casing pipe.

Wrapped Casing (Coated Pipe): A coating—usually composed of asphalt and asphalt-coated paper—on pipe for protection from corrosion. Some coatings may contain plastic, fiberglass, coal tar, or other materials.

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Part 2

PLANNING PHASE

The horizontal auger boring technique is a trenchless method for pipeline installations in places where open-cut construction methods are disruptive, not cost effective, or physically not feasible. There are other trenchless methods for installing pipes, and design engineers must examine all of the appropriate methods to determine the one that will best meet their project requirements and will allow for successful implementation under the given specific conditions that will be encountered during the process.

2.1 PREDESIGN SURVEYS

For successful execution of horizontal auger boring projects, a survey of the site conditions for surface features, subsurface geotechnical conditions, and utility data should be conducted and incorporated into the design process in its early stages. The design engineer must provide the contractor with sufficient information about the nature of the site and the possible obstacles. This will help in determining the suitability of utility installation with the horizontal auger boring method.

The predesign survey includes the investigation of general site conditions, examination of existing underground utilities and potential for obstructions, geotechnical investigations (including groundwater), environmental conditions, required drive lengths, pipe diameters, site access, depth, grade, tolerances, effect on surface activities, location of existing/abandoned/proposed utilities, and rights-of-way requirements.

2.1.1 Site Conditions and Surface Survey

A detailed survey of existing site conditions, both surface and subsurface, should be performed in the initial stages of planning. This information plays a vital role in determining the feasibility, alignment, gradient, and physical constraints of the proposed horizontal auger boring project.

It is important that adequate, detailed site investigation and relevant material testing be conducted. The jobsite should be thoroughly surveyed for surface features, such as overhead power lines, highway/railway crossings, existing grading contours, water drainage problems, availability of easements and rights-of-way, job access limitations, workspace limitations, and any other obstructions. A survey should be conducted to determine whether there is adequate space for boring pits, setting up equipment, and stockpiling material. Natural drainage gradient should be examined and considered to prevent jobsite flooding.

2.1.2 Subsurface Survey

The subsurface investigation can be initiated once the general site conditions and the surface survey data have been obtained with positive results. Subsurface data include the investigation of existing utilities and geotechnical properties.

The most critical aspect of the subsurface survey is locating the existing utilities. All of the utilities on the proposed path should be contacted, located, and plotted to avoid potential underground obstruction to the bore. This is especially important when a job requires work beneath a roadway. In such jobs, the potential for hitting a utility is very high, and damaging the utility lines will cause serious disruptions to traffic and great inconvenience to the public.

2.1.3 Geotechnical Investigation

Geotechnical investigation of the site should be performed to identify general and special subsurface conditions. Depending on the knowledge of known local geological conditions, the extent of the investigation may vary.

In areas where there are uniform soil formations, it may be possible to use existing data to identify the types of soil conditions that will be encountered. In areas where there are varying soil conditions, a preliminary investigation of the general types of geotechnical conditions should be undertaken. A typical geotechnical investigation consists of surface borings, soil samplings, and laboratory sieve analyses.

One of the most problematic ground conditions for horizontal auger boring is soil that contains boulders. Geotechnical reports should address the potential for encountering boulders, the sizes of the boulders, and the frequency of such encounters. The horizontal auger boring method can accept boulder sizes less than one-third of the diameter of the casing. Casing sizes, therefore, should be designed to accommodate the largest boulder that can be encountered.

A Geotechnical Baseline Report (GBR) prepared by the engineer must be made available to the contractor before bidding for the project. The

Geotechnical Baseline Reports for Underground Construction (a joint publication of the Underground Technology Research Council [UTRC], American Society of Civil Engineers [ASCE], and American Institute of Mining, Metallurgical, and Petroleum Engineers [AIME]) describes these reports in great detail. Readers are strongly urged to refer to this publication for more detailed information on GBR history, rationale, and preparation. The contractor is responsible for risks associated with conditions consistent with, or less adverse than, those indicated in the baseline report. However, if subsurface site conditions are significantly more adverse than reported in the baseline, the owner should pay the additional cost of overcoming those conditions. The report should contain, but not be limited to, the following information:

- Project description
- Available existing information/reports
- Description of the geology
- Generalized geological profile
- Groundwater conditions
- Presence of contaminants
- Geological features that may affect the project
- Man-made features that may affect the project
- Anticipated ground behavior at the shaft locations
- Anticipated ground behavior along the pipeline

Table 1 presents crucial subsurface parameters that must be supplied to the contractor for preliminary assessment.

TABLE 1. Crucial Subsurface Parameters Needed by Contractors.

Soil Parameters	Rock Parameters
Identification	Identification
Gradation	Color
Permeability	Grain size
Density	Composition
Standard penetration value (blow count)	Intact rock strength
Cohesion	Hardness
Moisture content	Quartz content
Atterberg limits	Fracture frequency
Unconfined compressive strength	Rock-quality designation (RQD)
	Total core recovery

2.1.3.1 Different Methods of Geotechnical Investigation. Subsurface investigation of soil deposits can be carried out using the following methods:

- Ground penetration radar (GPR)
- Acoustic (sonar) methods
- Geophysical methods
- Test pits or trenches
- Hand augers
- Boring test holes and sampling with drill rigs

Types of soil sampling include auger, split spoon, thin-wall (Shelby tube), and rock core sampling.

To identify the geological conditions along the pipeline alignment, a thorough subsurface investigation must be carried out in the planning phase. The anticipated geological conditions are the most important factors in project feasibility and risk analysis of any proposed horizontal auger boring project.

2.1.4 Utility Locating

Prior to the design of a boring project, all utilities should be located using nondestructive means. This process involves the use of several tools and includes, but is not limited to, a utility locator, a nondestructive digging device, and utility maps. After the depths and diameters of all utilities have been established, each utility is mapped or plotted and the new bore path is established to avoid current utilities.

2.1.4.1 Visual methods. The visual methods of locating utilities shall be limited to confirming the depth and size of utilities previously located by nonvisual methods.

Hand excavation. Hand excavation is normally used near existing utilities. Because some of the utilities may be unprotected or the utility may not be in the expected location, care should be taken to avoid damage.

Soil boring. Soil boring is the traditional method of determining the locations and properties of subsurface utilities. Because underground utilities can be damaged if struck, borings must be used with caution.

Test pits. The test pits can be excavated by a combination of machine and hand excavation methods. They create a sufficiently large hole for the direct physical examination of the in-place soil materials and any exposed utilities. Care must be taken not to damage utilities during the excavation process.

Vacuum excavation (potholing). This method is used to create 1-ft to 1.5-ft (300 mm to 450 mm) diameter holes to physically confirm the position and depth of an underground utility. A hole is cut in the road pavement using a rotary core drill, and the excavation is advanced using compressed air jets and/or high-pressure water jets. This excavation process does not normally damage existing utilities, and the hole in the street pavement is kept to a minimum, allowing for easy repair. This procedure can be used only to confirm the position of known utilities or previously located utilities.

2.1.4.2 ***Nonvisual/geophysical methods.*** Geophysical methods of locating underground utilities typically utilize a wave/signal that is introduced into the ground to map—based on ground response—the physical properties of the utility that is located.

Many of the methods can be used in several different arrangements that vary in terms of what can be detected, depths of penetration, sizes and types of objects that can be resolved, and implementation cost.

These units will provide only an estimate. Because of active interference and passive interference, the depth estimate can vary. Active interference is caused by a source that is emitting a signal that prevents the locator from working correctly (e.g., a radio station or building alarm system). Passive interference occurs when a signal is blocked or picked up by an item other than the utility being located (e.g., rebar, railroad tracks, or street plates).

The common type of locator requires that the utility have a metal base or tracer wire that can conduct the signal. The basic principle of this type of locator is the creation of an AC loop. This is accomplished by connecting the positive lead from the transmitter to the utility and the negative lead to a ground stake. The signal then travels down the positive lead to the utility, follows the utility to the next ground point, and travels through the ground back to the ground stake with the negative lead attached. In most cases, this same locator can be used to locate nonmetallic utilities, such as sewer lines, by inserting a small transmitter into the line and tracing the transmitter as it is moved through the utility. The receiver will locate the transmitter and provide a depth estimate of the utility relative to the transmitter.

For locating nonmetallic utilities, such as PVC water pipes, where it is not practical to insert a transmitter, GPR is often used; however, soil condition can limit GPR.

Once the utilities are marked, they should be exposed to confirm their depths and diameters. It is good practice to expose the utility in the bore path before the bore and to leave the utility exposed until the bore passes the utility.

2.1.5 Subsurface Utility Engineering

The Federal Highway Administration (FHWA) defines subsurface utility engineering (SUE) as an engineering process for accurately identifying the quality of subsurface utility information needed for highway plans, and for acquiring and managing that level of information during the development of a highway project.

The advantages of SUE include:

- Avoiding conflicts with existing utilities during boring operations.
- Reducing delays in construction schedules by eliminating unforeseen conflicts with the existing utilities.
- Eliminating the need for added construction costs caused by unexpected utility adjustments.
- Reducing greatly the chance of inconvenience to the public by damaging existing utilities during the boring operation.

2.2 JACKING PITS AND RECEIVING PITS

To avoid any hazard to the structures or to the public, boring pits should be located at a safe distance from existing structures. The distance between the pit and the roadway should be adequate to allow sloping of the pit if necessary. If constraints prevent sufficient sloping, an earth support system of pit walls should be considered. Enough room for safe loading and unloading of equipment and for spoil removal should be provided. Accidents are less likely to occur at sites that are open and clear of debris.

It is the responsibility of the contractor to make a safe pit that is in accordance with the rules set forth in the Occupational Safety and Health Administration (OSHA) Code of Federal Regulations, Construction Standards for Excavations, 29 CFR part 1926, subpart P. There are specific requirements for pit construction, protection, barricades, traffic control, installation, and type of ladders used in the pit and for personal safety equipment. Information can be obtained from your regional Department of Labor office.

Excavation can begin once the utilities are located and marked. The jacking pit should be offset more on the side of the bore line where spoil exits the auger. This facilitates the access for spoil removal. The utilities that are encountered in the pit must be properly supported. An adequate dewatering system must be installed if groundwater is expected.

The bottom of the boring pit should be filled with crushed stone or gravel to make it firm enough to support the boring machine tracks, boring machine, casing, and auger. Usually, wood planks measuring 2 in. (50 mm) × 8 in. (20 mm) × 16 ft (5 m) are placed parallel to the track rail, under the track, for support. A concrete floor may be poured if the bore is of considerable length, size, and duration and/or soil conditions warrant it. A concrete floor is recommended for projects requiring boring in rock. In all cases, the track support must be set to the proposed grade of the bore. Figure 1 shows the initial setup of the boring machine in the pit.

The boring machine exerts thrust on the back side of the boring pit. To withstand the thrust exerted by the boring machine, the wall will require the installation of a backing plate against the wall opposite the bore. The backing plate can be steel sheeting, steel plate, or timber for low- to medium-thrust pressures; a concrete backstop in addition to steel plate can be used if the thrust pressure is high. Adequate care should be taken to ensure that the thrust pressure developed by the operation does not affect existing utilities near the bore pit.

In most cases, an exit pit is required at the end of the bore. The safety requirements for an exit pit are the same as for an entrance pit. Unless absolutely necessary, no personnel should be allowed in the exit pit during the boring operation. As the casing pipe approaches the exit pit, care should be taken to prevent collapse of the pit walls.

The possibility of flooding always exists during the boring operation. The location of a pit sump for pumping should be considered during the design of the pit. The sump is placed on the right or left rear, depending on the slope of the pit floor. This placement will move water away from ejected spoil on the left side of the machine. Additionally, jacking and receiving pits can be used to verify geotechnical information.

FIGURE 1. Machine Setup in the Pit.

2.3 PIPE SIZE CONSIDERATIONS

The pipe diameter must be of sufficient size to meet the requirements of the project. The diameter of the casing must also be sized according to the largest boulder that may be encountered. The size of pipe or casing that can be installed by this method ranges from 4 in. (100 mm) to more than 72 in. (1,800 mm).

2.4 LENGTH OF THE BORE

The horizontal auger boring method was initially developed to cross under a two-lane paved roadway with an average length of 40 ft (12 m) and a maximum length of 70 ft (21 m). Since then, several innovations have enhanced the equipment capability by a large extent. The average bore now ranges from 175 ft (53 m) to 225 ft (68 m), with the maximum bore span being greater than 600 ft (180 m).

2.5 ACCURACY AND TOLERANCES

The accuracy of the bore depends largely on the initial setup, ground conditions, and the operator's skill. A line accuracy of ±1% of the length of the bore is normally achieved in typical horizontal auger boring projects. However, grade accuracy can be achieved by using line-and-grade steering systems.

2.6 COST CONSIDERATIONS

The cost of a horizontal auger boring project is influenced by several factors, including:

- Geotechnical conditions
- Location of the project
- Existing utilities along the alignment
- Groundwater
- Complexity of the project
- Depth of pits
- Diameter of pipe
- Length of the bore
- Number of bores on the job
- Mobilization, setup, and moving costs
- Required accuracy
- Market conditions

2.7 ENVIRONMENTAL AND SOCIAL BENEFITS

The horizontal auger boring method can significantly reduce the construction impact on environmentally sensitive areas. With rising concern over pollution due to construction and about work in sensitive areas such as wetlands and reserve forests, the Environmental Protection Agency (EPA) and other authorities are creating strict rules about workspaces in these areas. Construction work in environmentally sensitive areas such as wetlands, rivers, streams, natural habitats, public parks, and historic places involves a lot of risk and effort. Public criticism on surface disruption and administrative burdens tend to increase while work is carried on in these areas. The following aspects influence working in sensitive urban areas, such as hospitals and schools.

2.7.1 Environmental Benefits (Minimizing Noise, Vibration, and Pollution)

Noise and vibration are often associated with utility construction. To install buried utility lines, contractors have to cut open existing surfaces, such as pavements, using heavy machinery like jackhammers, backhoes, excavators, and/or trenching machines. These machines produce vibrations and noises that often lead to citizen complaints. Additionally, utility constructions tend to produce dusty conditions, and the serious health concerns associated with such conditions result in an obvious public nuisance. This problem is even more complicated in critical areas, such as schools and hospitals, and in areas of heavy urbanization, such as downtown areas and major business areas in big cities. Horizontal auger boring machines minimize the negative effects of noise, vibration, and pollution.

2.7.2 Social Benefits

There are several social benefits of using trenchless pipeline installation methods. The following are some of the major social costs, the impacts of which are reduced by using horizontal auger boring or any other trenchless method as opposed to the open-cut method:

- Less damage to pavement structure
- Minimum possibility of damage to adjacent utilities and structures
- Minimum vehicular traffic disruptions
- Less disruption of businesses and trade loss
- Enhanced safety

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Part 3

DESIGN AND PRECONSTRUCTION PHASE

3.1 FEASIBILITY AND RISK ASSESSMENT

The horizontal auger boring method can be used successfully in a wide range of soil conditions, ranging from dry sand to clay to solid rock formations. However, conditions like groundwater, flooding, and potential obstructions (e.g., boulders and existing utilities and other man-made obstructions, and unexpected geological conditions) may pose a challenge to horizontal auger boring projects. It is helpful to analyze thoroughly the suitability of the horizontal auger boring method under proposed site conditions.

3.2 STEEL CASING AND OTHER PIPE DESIGN

Typically, steel pipes are used for casing to prevent potential damage from the rotating augers. The casing should be new, of good quality, and well prepared. Machine-cut beveled ends ensure casing alignment, joint-end squareness and exact lengths keep the head at the correct location relative to the casing, and smooth walls reduce the required jacking force and the tendency of the casing to rotate during the boring process. It is recommended that all bores be done with a complete string of full-size auger sections. However, under conditions in which the auger loading is light and the spoil moves easily in the casing, lead sections of a full-size auger can be followed with smaller sections. A smaller-diameter auger is never used in the lead section of the casing. The step-down of auger size should not exceed one-third of the casing size in two step-down sizes. When this recommendation is neglected, problems normally occur. This decreases the efficiency because not all of the spoil is removed from the casing where the smaller-diameter auger is being used at the rate of excavation. This results in increased auger rotations to remove the volume of soil being excavated at the face, which again results in the rotation of the auger without forward advancement.

Other factors in the use of smaller augers are bending and torque. The undersized auger creates bending, which results in stresses in the auger stem. Also, the smaller auger will have more windup from the same torque loading than the full-size auger. Torque windup pulls the cutting head back toward the casing and could cause the wing cutters to contact the casing, further increasing torque and causing even more damage.

Wing cutters—devices attached to the cutting head—open and close. When the cutting head is rotated clockwise, the wing cutters open to provide overexcavation of the borehole. By minimizing casing skin friction, overexcavation of the borehole allows the casing to enter more easily. Wing cutters are used only in stable soil conditions and are never used with the cutter head inside the casing. The wing cutters are adjustable to control the amount of overexcavation. The standard over-cut is $\frac{3}{4}$ in. (19 mm) when not using a steering head and 1 in. (25.4 mm) when using a steering head. When the cutting head is rotated counterclockwise, the wing cutters close so that the cutting head can slide back inside the casing for auger removal. The wing cutters must not be set to overexcavate at the bottom of the casing. This causes the bore to drift in a downward direction. Overexcavation of the bottom can be prevented if the boring head is kept centered. This is accomplished by using new or built-up augers in the lead section of the casing. A worn auger in the lead section will allow the head too much freedom and the wing cutter pattern will be erratic.

3.2.1 Banding the Casing

The use of a partial band at the head end of the casing is recommended when boring in most soil conditions. The band compacts the soil and relieves pressure on the casing by decreasing skin friction. The banding process is most effectively utilized in unstable soil conditions where wing cutters are not used. In this case, the casing is pushed forward without the borehole being overexcavated. Therefore, the soil compacting benefit is more pronounced because it relieves the pressure on the following casing sections. It is also beneficial in rock or boulders because it strengthens the leading edge of the casing.

Placement of the band is a matter of personal, experience-based preference, but it is usually $\frac{3}{8} \times 6$ in. (10×150 mm), rolled to fit the casing. A gap of approximately 8 to 10 in. (200 mm to 250 mm) is left at the bottom. Place the band so that it leads the casing by about $\frac{1}{2}$ in. (12 mm). Weld securely along the front on the inside and along the rear on the outside. The inside chamfer of the front weld will provide a lifting action for the casing if the thrust is rapid. If wing cutters are used to overcut the casing, a falling action will occur. Figure 2 illustrates a typical banding of the casing.

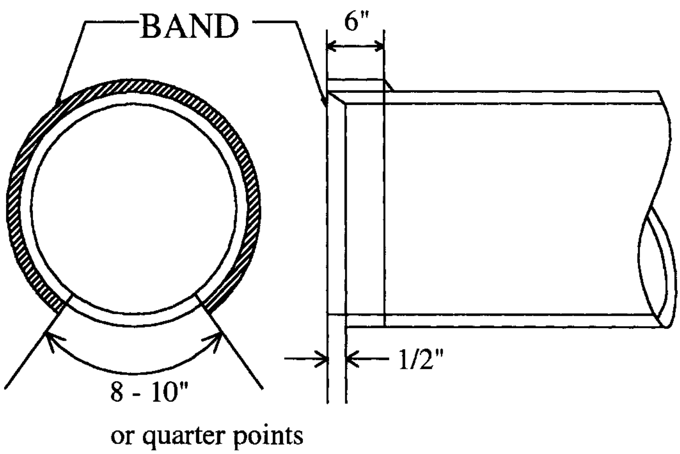


FIGURE 2. Banding the Casing.

3.2.1.1 Installation of casing. Collaring is the first operation in beginning a bore. The objective is to start the cutting head into the ground without lifting the casing out of the saddle. This is done by rotating at low revolutions per minute (RPM) and using a slow thrust advance. When approximately 4 ft (1.3 m) of casing has entered the ground, the engine is shut down, the saddle is removed, and the line and grade of the casing are checked. If the casing is not in line with the proposed bore, the casing is removed and the process is repeated. The success of the bore depends, to a great extent, on the line and grade of the first section of the casing. Figure 3 presents a sample horizontal auger boring cutting head.

FIGURE 3. Sample Horizontal Auger Boring Cutting Head.

After the first section of the casing has been installed in the ground, the casing is cleaned by rotation of the auger until all the spoil is removed. The machine is then shut down, and the auger pin in the spoil chamber is removed. The machine is then moved to the rear of the track and is again shut down. Then the next section of the casing and auger are lowered into position. The augers at the face are aligned flight to flight, the hexagonal joint is coupled, and the auger pin is installed. Steel bar stock, set on edge, is welded on the casing to be installed at the 11 and 1 o'clock positions. The casing is then advanced over the auger. The second casing is aligned with the first casing by resting the bars on top of the installed casing and using minimum 4 ft (1.2 m) straight edges along the top and the sides. If the second casing is in line with the first casing and seriously out of line at the machine end, it means that the first casing is misaligned and must be corrected, or it will result in an unacceptable bore alignment. The first casing should have waterline and lubrication lines already in place. Once the second casing is aligned with the first casing, the two are tacked together and welded completely. The drive is then coupled to the auger, and the casing is secured to the pusher. Water and lubricant lines, if being used, are added. The machine is then started, and the casing is installed. The process is then repeated until the bore is completed.

3.2.2 Casing Sizes

The typical size of the casing ranges from 4 in. (100 mm) to 72 in. (1,800 mm) or more, dependent on the project requirements.

3.2.3 Casing Wall Thickness

The pipe wall thickness commonly ranges from ¼ in. to 1½ in. (6 mm to 38 mm), based on the pipe sizes, project conditions, and required strength.

3.2.4 Mid-Weld

A mid-weld is sometimes used for 48-in. (1,200 mm) and larger diameters. The weld should be proper to avoid leakage and infiltration.

3.2.5 Installation Loads

The casing should have sufficient strength to withstand the installation loads, friction, and thrust applied by the boring machine.

3.2.6 External Loads

Since the pipes installed by the horizontal auger boring method normally pass under highways and railroads, there is a considerable amount of loading on the pipes. Much thought should be given to selecting the wall thickness and the strength of the pipe installed, especially if the pipe is shallow.

3.2.7 Steel Pipe Corrosion Protection Considerations

Generally, the casing thickness that is used for horizontal auger boring is sufficiently thick that corrosion protection coatings are not required. Since any coating on the casing pipe will be damaged during installation from the rotation of the augers and/or the casing being jacked through the soil, coating is not recommended. It is, however, recommended that a pipe with greater wall thickness be used to increase the longevity of the pipe.

3.3 CARRIER PIPE DESIGN

After successful installation of casing pipe, the carrier pipe (also called product or distribution pipe) can be installed. Carrier pipe is installed by first attaching wooden skids or premanufactured casing spacers to the carrier pipe before assembly. The carrier pipe is then installed, one piece at a time, from either the entry or exit pit. It can be installed by pushing by hand or with a boring/jacking machine or by pulling with a winch or other methods.

3.3.1 Blocking/Spacers

For gravity sewer installations, where installation of the carrier pipe on line and precise grade is necessary, it is extremely important that the carrier pipe be blocked down to prevent flotation. This can be accomplished by using a differential wood blocking banded to the carrier pipe to allow for adjustment of the grade inside the casing.

Another method of carrier pipe installation is the use of premanufactured spacers or casing insulators. These spacers come in plastic, fiberglass, stainless steel, and carbon steel. They can also be coated in epoxy, rubber, and various other materials. Manufacturers provide recommendations for design and spacing of the spacers. If the carrier pipe is properly supported with spacers, sometimes there is no need for any fill inside the annular space between the carrier pipe and the casing. A further advantage is the ease with which the carrier pipe can be removed if future maintenance becomes necessary. Casing spacers can be ordered to place the carrier pipe accurately on exact grade.

3.3.2 Internal Casing Grouting

After the carrier pipe is blocked inside the casing, grout or sand backfill can be used in the annulus of the pipe. Lightweight cellular grouts are an excellent product for this application. Compared with regular sand-cement grouts, cellular grouts have a lower density that reduces flotation of the carrier pipe, and they have superior fluidity, allowing for low-installation pressure. Usually, a compressive strength of 150 psi (10,342 kPa) is adequate. Care must be taken when using regular sand-cement grout for small pipes in a large annulus, because the heat of hydration of the sand-cement can be significant enough to cause damage to some plastic pipes. Grouts also have some disadvantages. First, with the use of grout in the annular space, removing carrier pipe for future maintenance, if necessary, is almost impossible. Second, grout is far denser than most carrier pipe, even if the pipe is capped and filled with water. There is a very real potential to "float" the carrier pipe if grout is used. Plastic pipe has become larger and lighter over recent years, making it more prone to floating and "hammering"; however, lightweight, low-strength cellular or bentonite grout can overcome most of these problems.

Because sand and pea gravel do not have sufficient strength to hold the carrier pipe down and keep it from floating, blocking the pipe down is important when using sand. This is especially true with larger-diameter pipes. Carrier pipes sometimes displace sand and pea gravel, even if the annular space between the carrier and the casing is entirely full. Sand and pea gravel are abrasive and may damage the pipe. The installation process involves using air to jet the material inside the casing under high pressure. Smaller casings that do not allow personnel-entry are very difficult, if not impossible, to fill completely. It is common to have joints separated or to actually blow holes in the pipe.

Certain conditions, such as the presence of high groundwater, may necessitate filling the annular space, and not using grouts may pose problems.

3.3.3 Hydrostatic Pressure

The hydrostatic pressure of the carrier pipe has to be considered in the design of the carrier pipe.

3.3.4 Corrosion Protection

Sufficient corrosion protection treatment should be given to prevent the carrier pipe from corrosion. There are different types of pipes available that are highly resistant to corrosion.

3.4 TRACKING, LOCATING, AND GUIDANCE CONSIDERATIONS

3.4.1 Waterline System (Grade Only)

The water level is a device to measure the grade of the casing pipe as it is being installed. It permits the monitoring of grade by using a water-

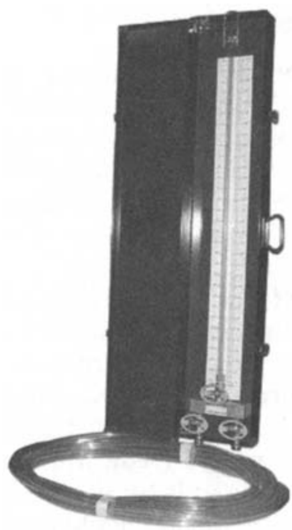


FIGURE 4. Sample Casing Grade Indicator.

level sensing head attached to the top of the leading edge of the casing. The level operates in the same way as the sight tube on a boiler. Both ends of the system are vented to ambient pressure. A pit-mounted control and indicator board is located at some convenient point in the pit near the operator. A hose connects the bottom of the indicator tube to a water pipe running along the top of the casing. Water is used to fill the system. The level of water in the pit indicator will then show the level of the valve at the end of the casing as it is pushed into the ground. When using this system, care must be taken to ensure that the system is full so that an incorrect reading is not obtained. Figure 4 illustrates a sample grade indicator, and Figure 5 presents the water pipe setup over the casing connecting to the grade indicator.

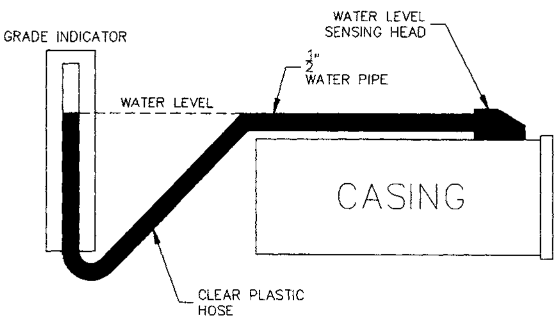


FIGURE 5. Water Pipe Setup over the Casing.

3.4.2 Line-and-Grade Systems

The most common method to control line and grade is through the use of a mechanical steering head that is incorporated into the lead piece of casing. Various new technologies have been, and are being, developed to achieve better results on both line and grade. These technologies include mechanical line and grade control heads, inertial guided systems utilizing gyroscopes, laser-guided systems, and walkover locate systems.

3.4.2.1 ***Mechanical line and grade control head.*** Line and grade are controlled using a patented technique using biaxial hinges. In the mechanical line and grade control head, the grade is monitored by using a water level and the alignment is monitored using a sonde transmitter and a receiver on the ground surface. There are two sets of steering rods that are used for making the corrections for line and grade. Miniature gearboxes are used to reduce the effort to turn the rods for line and grade control on long bores. The leading edge of the casing should be properly prepared, and care should be taken to minimize torque and thrust and to keep the casing along the design alignment. To control the line, a proposed alignment is marked on the surface above the proposed bore. As the bore progresses, the offset is measured from the proposed line and the corrections made to compensate for it. The limitation of this method is that the surface above the bore must be accessible to take readings for controlling the line.

3.4.2.2 ***Electronic (inertial) line and grade control head.*** This computer-aided technology permits the steering head to be controlled hydraulically and electronically, while the location of the steering head is monitored by using highly sensitive gyroscopes. The gyroscopes measure the deviation of the pipe installation from planned line and grade and display the information on the computer screen. Based on this information, the line and grade can be corrected manually by using a joystick, or the corrections can be automatically made by the computer. The advantage of this method is that, since this is an inertial system that uses gyroscopes to measure the deviation from planned line and grade, the readings are not affected by any other magnetic fields. Hence, the degree of accuracy is very high. This permits installations to a very precise line and grade, even under built-up areas or areas that are affected by magnetic influences. Currently, the size of the tracking devices limits the minimum diameter of installation to 36 in. (900 mm), but there is no upper limit.

3.4.2.3 ***Walkover system with water level for line and grade.*** The system consists of a walkover receiver, a cable-ready remote display with a power supply, and a sensitive pitch cable transmitter. This particular transmitter is used exclusively for installing gravity flow pipes, where precise grade control is required. The transmitter will read both positive and negative grades with equal accuracy.

The transmitter is connected with a wire the length of the bore to a display located at the operator's station. The wire powers the transmitter and carries the pitch/roll data back to the display. The steel of the casing acts as the ground connection. Because the transmitter is mounted on the lead casing, the display provides the operator with its real-time pitch and roll position. This instantaneous information allows the operator to react to any grade deviations and to identify if the forward shield has begun to roll in either direction.

The auger's heading can be determined by using the locate points. The front locate point is found at approximately 70% of the depth in front of the transmitter, above the ground surface. The distance of the transmitter located using the walkover receiver depends on the type and capability of the transmitter used.

3.4.2.4 Laser-guided tunnel attachment for line and grade installations. In a laser guidance system (such as bores head method), the laser beam is shot at a target located near the cutting head. Any deviations in line and grade can be noted when the laser beam is off target, and the head can then be steered to the right path. The augers rotate inside a smaller pipe inserted inside the casing pipe. The laser beam runs above the boring machine to the target behind the auger head. Figure 6 shows the boring machine tunnel attachment setup.

3.5 CONTRACT DOCUMENTS

After the completion of the design phase by the engineer, he or she and the owner prepare the bid/contract documents. The contract documents should provide all of the necessary information for the contractor to prepare bids, to plan the work, and ultimately to execute the pipeline installation. It is important that the contract documents be complete, clear, and concise and that they be prepared by individuals with experience in the specified methods and technology. These documents may include, but are not limited to:

- The scope of work and special conditions
- Drawings
- Technical specifications
- Geotechnical information

3.5.1 Scope of Work and Special Conditions

The contract documents should provide information about the scope of work and special conditions of the job. The general conditions include the

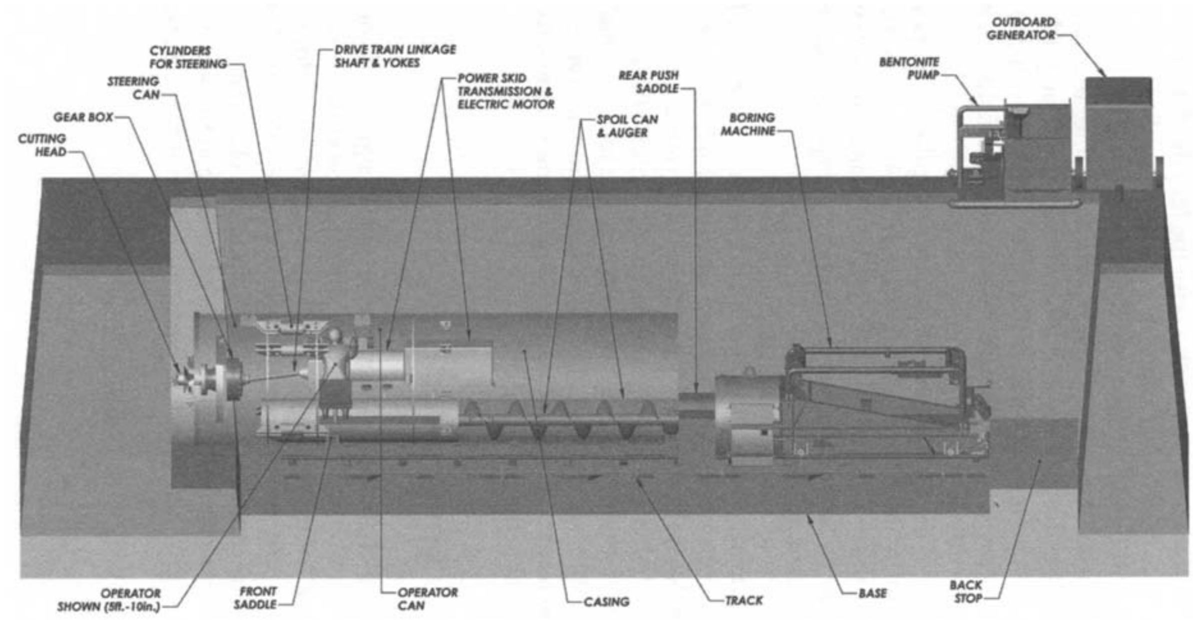


FIGURE 6. Section of Boring Machine Tunnel Attachment.

type of job, amount of work, and other relevant data for the contractor. Special conditions include information about specific tasks or characteristics about the job. Any other information available about the jobsite should be included in the contract documents.

3.5.2 Drawings

Contract documents must include all relevant drawings for the site. Care should be taken in detailing special conditions and tasks on the job. Drawings on the project should provide information about the jobsite condition, depth of installation, length of the pipe to be bored, and orientation of the boring. The drawings also show all the known utilities in the vicinity of the proposed pipeline. The contractor should check for details on the project in the drawings and, if any information is missing, should report the matter to concerned authorities. Drawing should be prepared by an engineer or any other person who has the authority to make the changes or drawings.

3.5.3 Technical Specifications

Detailed specifications on the project should be included, along with other documents related to the job. Technical details, such as the diameter of the pipe, type of pipe, method of installing the pipe, and pertinent soil conditions, should be included in the documents. Any other technical specifications relevant to the job should be made available to the contractor.

The technical specifications should include:

- Required accuracy in line and grade of the bore
- Casing diameter, wall thickness, length, grade, and strength
- Type of joining system
- Product pipe
- Blocking or spacers for carrier (product pipe) installations
- Grouting
- Site restoration

3.5.4 Geotechnical Information

All geological and geotechnical information available to the owner should be detailed in the geotechnical report. Information about the type of soil, groundwater conditions, water table, and information about the existing utilities are to be detailed in the geotechnical information. (see **Section 2.1.3**).

3.6 DIFFERING SITE CONDITIONS

If site conditions are significantly different from those described in the contract documents and the contractor can show that the different conditions adversely impacted the work, the contractor should be entitled to some form of compensation. Preliminary investigations, such as utility mapping and geotechnical survey, would avoid most of the common obstructions occurring during the boring operation. A risk-sharing strategy, such as one recommended by the American Society of Civil Engineers (ASCE) Geotechnical Baseline Report, is strongly recommended. Some situations that can create differing site conditions are:

- Boulders
- Soft ground bores that encounter rock
- Rock bores that encounter soft ground
- Stable soil conditions that change to unstable flowing sand conditions

3.6.1 Existing Utilities

Existing underground utilities should be located and exposed before proceeding with the work. The contract documents should clearly identify responsibilities of the owner and the contractor in locating existing utility lines. The existing utilities should be identified in the contract drawings. Damage to adjacent utility lines is a major concern to any underground boring operation and should be avoided at all costs. A huge amount of money can be collected as compensation if there is any damage to the existing utilities (see **Section 2.1.2**).

3.6.2 Different Soils

Geotechnical data, included with the contract drawings, provide information on the expected soil conditions at the place of work. Oftentimes, during work on the project, unexpected changes in soil condition can create costly situations. Changes in soil conditions, such as changes in groundwater, loose sand, boulders, or mixed face, can create situations that can halt a horizontal auger boring operation.

3.6.3 Rocks and Boulders

Major obstructions for a boring operation can be in the form of boulders and rocks directly in the bore path. Preliminary investigation should be conducted to determine the location of any such rocks or boulders. In case of such obstructions, alternate routes or bore paths should be established to avoid damage to the equipment and to decrease the cost of the project. If alternate bore paths are not available, the diameter of the casing should be large enough to remove the boulders through the augers. Generally, a boulder one-third of the diameter of the casing is the largest boulder that can be removed through the augers. Costs associated with the removal of these boulders should be considered extra work. Other methods, such as hand mining, should also be considered based on the anticipated soil conditions.

3.6.4 Water Table

Water in a boring operation can be disastrous. A preliminary survey should be conducted on the site to study the existing water table conditions before commencing on the project. Proper dewatering techniques must be implemented to pump out water. Note that water table conditions may change during different times of the year.

3.7 CONTRACTOR PREQUALIFICATION

Usually, the general contractor subcontracts the horizontal auger boring operation, and the owner or government agency does not get directly involved with the qualifications of the boring subcontractor. However, it is recommended that the general contractor check the background, experience, and reputation of the subcontractor and the operator before awarding the subcontract. The owner can request to check the qualifications of the horizontal auger boring subcontractor as a quality assurance measure in critical crossings.

3.7.1 General Information and History

Companies are required to provide information on the type of organization, type of works undertaken, and type of personnel involved in the project during the first part of the program.

- Name and type of organization (corporate, partnership, etc.)
- Type of contracting business
- Type of projects
- List of individuals working for the company
- List of the projects completed
- List of affiliate, partner, or subsidiary companies
- Organizational setup within the company
- Completion rate of the awarded projects

3.7.2 Experience and Equipment

Contractors are commonly required to provide information on the type and quantity of the equipment owned by the firm and the capacity and durability of that equipment. Experience of the personnel and the experience of the firm as a whole will be considered during the prequalification requirement.

- List of equipment owned (including name, description, quantity, and capacity)
- Type of work performed
- Type of work performed using own crew
- Safety records

3.8 DISPUTE RESOLUTION

Because there is a high chance of encountering unforeseen conditions underground, it is imperative that a well-devised dispute resolution plan be included in the contract document. A Differing Site Conditions (DSC) clause (see **Section 3.6**) should be included in the contract to allow the contractor to be compensated for extra costs involved without being forced into a breach of contract. It is in everyone's best interest to resolve conflicts quickly, fairly, and equitably.

Part 4
CONSTRUCTION PHASE

4.1 WORKSPACE

The workspace should provide enough room for the safe operation of equipment and for storing the materials. Workspace includes both the space available on the site and the space inside the pit. The space inside the pit should allow free movement of personnel and equipment. The pit should be large enough to permit the personnel to work around the pipes for jacking, to attach and detach pipes. The space should also be large enough for the crane to lower the new pipes into the pit and for the excavator to remove the spoil from boring. The jobsite layout should be well planned to facilitate storage of various materials and equipment required for the job.

4.2 JOBSITE LAYOUT

The jobsite layout should be prepared well in advance, before commencement of work on the site. The layout should provide adequate space for storage of equipment, material, and job trailers. The material required for the job, such as augers, casings, pipes to be installed, and lubrication systems, should be in a close proximity to the work pit. Material storage should be well planned to reduce the travel time for easy handling. The equipment required for the job, including the generator to supply power and the welding machine, should be located close to the work pit to facilitate the job. Other equipment, such as a crane or an excavator, should be placed in a position with enough room to maneuver around the work pit. Care should be taken in locating the equipment around the work pit so that pieces of equipment do not compete with one another for space to work. For work on the project to run smoothly, permits and rights-of-way should be procured well in advance. While venturing into adjacent properties for pit excavation or workspace around the work pit, permission to do so should be obtained and justified with proper compensation. Local authorities should also be notified of the job, and one should seek permission from them before proceeding with the work. A typical jobsite layout should permit:

- Storage of materials (pipe sections, augers, bentonite bags, etc.)
- Lubrication system
- Support equipment (backhoe, forklift, crane, etc.)
- Easements and rights-of-way

4.3 PITS

A horizontal auger boring operation requires two work pits, one for boring, called the entry pit, while the other is called the exit pit. The pit required for boring should be big enough to facilitate the boring operation. It should be designed to include the auger machine, the rails, a thrust block, and the hydraulics to provide the jacking force along with space for a few personnel. Personnel working in the pit include the operator of the jacking machine and two to three people, depending on the job, to remove the spoil. The pit should be properly shored to prevent it from collapsing. Figure 7 illustrates the cross section of the pit with equipment setup.

- Pit design. See **Section 2.2.**
- Excavation techniques
  - The excavation technique depends on the size of the pit and the availability of the equipment.
  - The excavation of the pit should be carried out using proper equipment. The pit should not be excavated too deep or too big

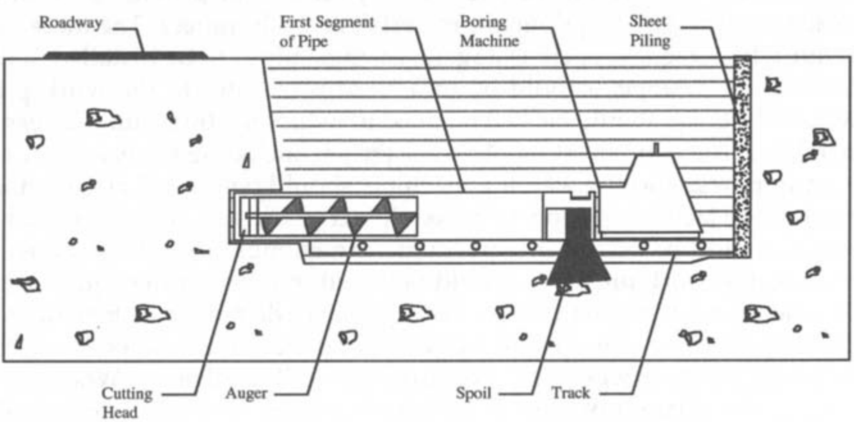


FIGURE 7. Cross Section of Typical Pit with Equipment Setup.

beyond what is required as specified. After excavation, proper techniques should be used to secure the walls of the pit, such as shoring or sheet piling.

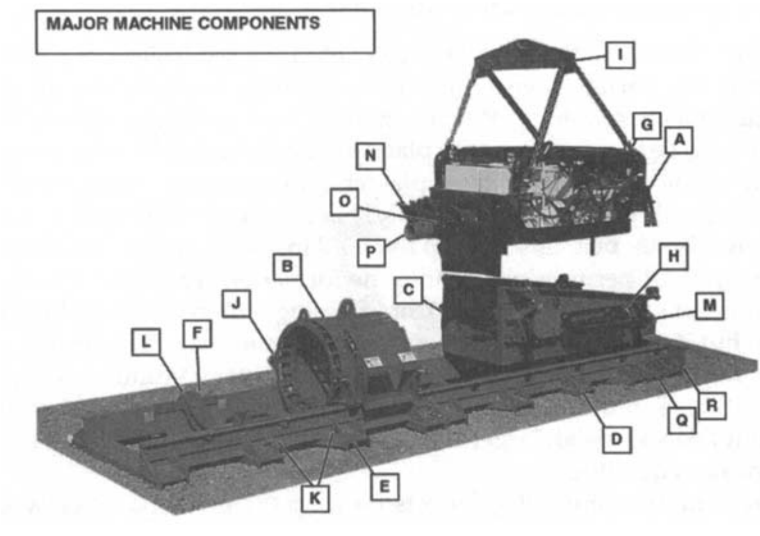
4.4 EQUIPMENT

Equipment should be selected based on the requirements of the horizontal auger boring project. The locations of major components and normal accessories of a typical horizontal auger boring machine are illustrated in Figure 8.

4.4.1 Attachments

Horizontal auger boring attachments include:

- Steering kit
- Different sizes of cutter heads



A Power Package
B Master Casing Pusher
C Base Push Unit
D Master Track
E Extension Track
F Master Saddle
G (4) Lift Points – Power Package
H (4) Lift Points – Base Push Unit
I Spreader
J Casing Attachment
K Track Pick-Up Locations
L Saddle Attachment
M Push Bar
N Spoil Ejectors
O Front Drive
P Front Drive Adapter
Q 2-ft Pup Track
R Push Plate

FIGURE 8. Components of a Typical Horizontal Auger Boring Machine.

- Casing adapters and saddles
- Master casing pusher

4.4.2 Steering Systems

See **Section 3.4.**

4.5 LUBRICATION FLUIDS

The lubrication fluids in horizontal auger boring applications are used in the annular space between the casing pipe being installed and the native formation, primarily to reduce friction on the casing pipe. Lubrication is also usually used for pulling or pushing in the product pipe inside the casing.

4.5.1 Filtration Control and Filter Cake

The lubrication fluid needs to be kept in the borehole or annular space during the boring operation. This is done by using bentonite or bentonite/polymer systems. When bentonite is properly mixed, it is sheared apart into very small, flat, thin platelets. These bentonite platelets act like small shingles and shingle or plaster off the inside of the borehole by forming a filter cake or wall cake. This filter cake will then be of sufficiently low permeability to keep the fluid inside the annular space instead of filtering or permeating out into the formation. The water phase of the fluid is not entirely eliminated from filtering into the surrounding formation, but it slows the filtration process tremendously. This is one reason that the lubrication ports on larger-diameter pipes continuously replenish the lubrication fluid that has filtered out over the longer period of time than it takes to install larger-diameter pipes. This filter cake has excellent lubrication qualities.

In sand, the bentonite platelets plug up the pore spaces between the sand grains. This allows the bentonite platelets to form a grout-like layer, plugging the porosity and permeability of the sand. In clay or shale, the filter cake reduces the amount of water phase that is allowed to filter out into the formation. This reduces the tendency to swell and become sticky that usually characterizes native clay and shale.

In a lubrication fluid, a higher concentration of bentonite platelets is created per gallon of water than is commonly needed for other drilling disciplines. This causes more viscosity, but higher viscosity in this case is a by-product of the need for higher bentonite concentration. In most cases, the closer we can get to bentonite sludge while still being able to pump it, the better.

The amount of lubrication fluid needed may vary, depending on the ground conditions and volume of the annular space.

4.5.2 Types of Lubricants

The commercially available lubricants are used for different applications based on the composition of the lubricant. Some of the lubrication products are designed to provide higher viscosities at lower concentrations of product by adding certain additives. These products are referred to as *beneficiated* or *extra high yield lubricants*. These products are in fairly common use and are usually mixed at a rate of one sack (50 lbs) per 100 gal (378.5 l) of water.

In the past few years, however, products have been developed that are more specifically designed for trenchless applications. These products have been designed to provide lower filtration rates, improved filter cake quality, improved suspension and stabilization, and increased lubricity with lower viscosity. This type of lubricant blend either allows improved pumpability because of lower viscosity or allows us to increase the lubricant concentration by 25% to 30% over the beneficiated products while maintaining the same pumpability. This type of product has certain ingredients added for specific purposes other than viscosity. Because of these additives, the product is a bit more expensive.

The cost increase, however, is more than offset by the 25% to 30% reduction in jacking forces that are generally seen with this type material, as opposed to the beneficiated products.

4.5.3 Lubrication System

The lubricant is normally mixed using a lubrication pump and flows through the pipes by means of conduits. The lubrication fluid is circulated to the exterior of the pipe through means of openings at regular intervals. Lubrication is recommended for all but very short jacks (under 100 ft/ 30.5 m). Figure 9 presents a typical lubrication pump.

FIGURE 9. Lubrication Pump.

4.6 RECOMMENDED PROCEDURES FOR VARIOUS GROUND CONDITIONS

Horizontal auger boring is a very versatile method that can be used in a wide variety of soil types. The following are the recommendations for horizontal auger boring used under different soil conditions:

4.6.1 Wet, Running Sand

The cutting head should be run inside the casing about one to two times the diameter of the casing being drilled. For example, on a 24-in. (600 mm) bore, the cutting head should be 24 in. (600 mm) to 48 in. (1,200 mm) back from the end of the casing, depending on the soil conditions. Because the cutting head is run inside the casing, wing cutters cannot be used. An overcut flat band should be used. The rate of penetration should be fast while the auger is turned slowly. The pressure should be monitored to determine the rate of penetration. Long bores require the use of lubricant and continuous installation. A steering head does not effectively work in this type of soil and should be avoided. The use of a sand auger is recommended. A sand auger is an auger section specially built for sandy situations with a smaller pitch than a regular auger section. A high degree of operator skill is required when boring in wet, running sand. Because of the risk associated with voiding of the soil, horizontal auger boring is not recommended in wet, running sand.

4.6.2 Wet, Stable Sand

The cutting head should be run flush with the end of the casing. An overcut band should be used. The rate of penetration should be fast while the auger is turned at medium speed. Long bores require the use of lubricant and continuous installation. A steering head may be used in this type of soil but may not be effective. If a steering head is used, then wing cutters should also be used. When using a steering head, a strong, lightweight sheet metal can be used to cover the gap where the steering head hinges. The sheet metal should be welded to the front steering section only. A sand auger should be used for insurance against pockets of runny sand.

4.6.3 Dry Sand

If the sand is stable, then the cutting head should be recessed inside the casing for about one to two times the size of casing, and the auger should be turned slowly. An overcut band is also advised. The rate of penetration should be fast while the auger is turned slowly. The use of lubricant is highly recommended. Long bores may require continuous installation.

However, in most situations, the main problem with dry sand is the running action of the sand and the subsequent void condition. To prevent this problem, remove the cutting head completely and run the lead auger inside the casing about 12 in. (300 mm) or the equivalent of the casing diameter, whichever is greater. The use of a steering head is not recommended in this soil condition. The use of a sand auger is recommended. A high degree of operator skill is required in this soil condition.

4.6.4 Dry Clay

The cutting head can be flush or just ahead of the end of the casing. An overcut band is advised. The rate of penetration should be fast while the auger is also turned fast. Long bores may require lubrication. Wing cutters should be used on the cutting head to provide an overcut. The problem with clay is that it tends to ball up and stick to the turning auger. Water should be added to the inside of the casing to lubricate the clays and get the cuttings out. A steering head can be suitably used in dry clay.

4.6.5 Wet Clay

The cutting head should be run flush with the end of the casing. An overcut band is recommended. The rate of penetration should be fast while the auger is turned at medium speed. The use of wing cutters is optional, depending on the stiffness of the soil. Long bores may require lubrication. A waterline should be used to add water to the inside of the casing to lubricate the clays and get the cuttings out. A steering head may be used in wet clays.

4.6.6 Small Gravel

The cutting head should be just ahead of the end of the casing. An overcut band should be used. The rate of penetration should be medium while the auger is turned at medium speed. Long bores may require lubrication. Wing cutters should be used on the cutting head to provide an overcut. A steering head may be used in small gravel.

4.6.7 Hard Pan

The cutting head should be just ahead of the end of the casing. An overcut band should be used. The rate of penetration should be medium while the auger is turned slowly. Long bores may require lubrication. Wing cutters should be used on the cutting head to provide an overcut. A waterline is used to add water to the inside of the casing to get the cuttings out. A steering head can be used in hard pan. If there is a potential for rocks and boulders to be encountered in the hard pan, consideration should be given to the casing size. A 30-in. (750 mm) diameter or larger casing should be used if boulders are present that would allow for worker entry if necessary.

4.6.8 Soft/Solid Rock

The cutting head should be ahead of the end of the casing. A rock head equipped with wing cutters should be used. The auger speed should be medium with an extremely slow rate of penetration. An overcut band and a lubrication line should be used. In the middle of the bore, it may be necessary to replace the teeth on the cutting head by pulling out all of the augers. A high degree of operator skill is required in this soil condition.

4.6.9 Large Gravels/Small Boulders

The horizontal auger boring method is not recommended for this type of installation. Another method, such as hand mining, should be considered. There have been some recent developments in adopting horizontal auger boring equipment that spins a casing through the soil. In this method, a thick wall casing is used. Instead of a cutting head, the leading edge of the casing is fitted with rock-cutting teeth similar to a hole saw. The teeth are placed at equal spaces in a sawtooth layout, with the alternate teeth pointed in and out. Stabilizer bars are welded on the outside so that the casing remains concentric in the bored hole. Inside the casing, deflection fins are welded so that the spoil inside the casing is pushed out toward the pit. The setup is identical to horizontal auger boring; however, no auger is used. The boring machine has a casing spinning adapter on it. The casing is attached to the casing spin adapter, and the whole string of casing is turned with the boring machine as the bore progresses. There is no steering control while using this method.

4.6.10 Hard Rock

For drilling through hard rock, the following methods could be used:

- ***The drill stem method.*** This method utilizes roller cone drilling bits to install a pilot hole with drill steel that is then enlarged to the final size by utilizing a reaming head. There is no steering control with this method.
- ***Rock disk cutter technology.*** This method utilizes a specially designed cutting head that is welded to the lead piece of the casing. This head is fitted with rock-cutting disks that cut the rock. A thrust bearing is used in the head to allow for the thrust of the cutting head to be placed through the casing and not through the augers.

- ***The casing spinning method.*** In this method, the leading edge of the casing is fitted with a roller cone cutting head. In this case, there are no deflection fins inside the casing. However, there is a water swivel that is at the boring machine end of the casing. While the boring machine turns the casing and applies a steady pressure on the face of the rock, the cutting head breaks the rock into fine cuttings. At the same time, water is pumped inside the casing through the water swivel. This serves two purposes. It cools the cutting head and washes the cuttings off the face and brings it out to the installation pit around the casing being installed. There is no steering control while using these methods.

4.7 PRODUCTIVITY

The productivity of a horizontal auger boring operation depends largely on the site conditions, required accuracy, project-specific conditions, welding and setup time, quality of the casing pipe, horizontal auger boring equipment, and the experience of the contractor and the operator. The average productivity for a typical job is approximately 30 to 40 ft/day (9.1 to 12.2 m) (approximately two casings a day), depending on the above conditions.

4.8 WORK PLAN

The work plan should include the following items:

- Permits
- Excavation techniques
- Responsibilities for design adequacies
- Supervision
- Inspection
- Protection of adjacent structures
- Public safety
- Ventilation requirements
- Method of spoil removal from pit (skid steer, backhoe, crane and bucket, vacuum, etc.)

A contingency provision for removal of possible contaminant soil can be included in the plan. Also, contingency plans should be provided for unexpected subsurface conditions and occurrence of obstructions. For pit excavation and boring operations, all OSHA rules, and those in the manufacturer's equipment safety and operations manual, should be followed.

In general, all DOT and railroad guidelines for depth of cover should be followed for planning and during the installation.

4.9 DEWATERING

Dewatering should be done in places where there is a high groundwater table to prevent flooding and facilitate the horizontal auger boring operation. The contractor should be responsible for the design, construction, operation, and maintenance of a dewatering system that meets the needs of the construction method. The water table should be at least 2 ft (0.6 m) below the bottom of casing.

Factors affecting the method of dewatering used include:

- The nature of the soil
- The groundwater hydrology
- The size and depth of the excavation
- The proposed methods of excavation and ground support
- The proximity of existing structures, and their depth and type of foundation
- The nature of any contamination at the site

4.10 INSPECTION AND MONITORING

- Preinstallation
  - —Alignment of the track for proposed grade of bore path.
  - —Before casing enters the embankment, a thorough inspection should be performed for line and grade.
- Postinstallation and damage correction
  - —Prepare an as-built drawing.
  - —Amount of spoil removal should be checked for possible voids outside of the casing. Any voids need to be grouted with approved grouting materials and methods.
  - —In sandy or unstable soil conditions, there is a possibility of void formation in the line of bore. In this condition, grouting of outside of casing is strongly recommended.

4.11 AS-BUILT DRAWINGS AND DOCUMENTATION

The following information should be documented in a horizontal auger boring project:

- Documentation of bore path endpoints
  - —The entry and exit points of the bore should be determined and should be documented before the boring operation.
- Required measurements prior to commencing boring operations
  - —A detailed survey should be done to determine the length of the bore and the proposed line and grade.
- Pilot hole as-built drawings
  - —As-built drawings that document the actual path of the pilot bore should be made after the bore is completed.
- Surface monitoring system
  - —Survey points on the surface must be established to check possible settlement and heave. DOT and railroad guidelines must be checked for allowable tolerances.
- Postinstallation survey
  - —The postinstallation documentation should include the actual line and grade achieved and possible damage to existing utilities.
  - —Other parameters that may be monitored are:
    - Jacking force
    - Pipe level
    - Pipe alignment
    - Lubricant pumped
    - Quantity of spoil removed

4.12 MEASUREMENTS AND PAYMENTS

- Types of payments
  - —The most common method of payment is by unit price per linear feet (LF) of casing actually installed. Details can be worked out between the general contractor and the boring subcontractor regarding the scope of work performed.
  - —Another method of payment is by lump sum. Again, the scope of work needs to be clearly determined.
  - —In certain conditions, such as fast-track projects, cost-plus (time and material) can be used.

4.13 TYPICAL COSTS FOR HORIZONTAL AUGER BORING

Below are sample costs for horizontal auger boring for a two-lane highway crossing. These costs vary with soil conditions, project-specific conditions, and scope of the job and do not include the cost of pit and casing pipe. It should be noted that, contrary to other projects, for horizontal auger boring, as length of bore increases, price per foot increases. This is because there is a higher risk involved with longer bores, and among other factors, bigger auger boring machine and auger equipment are required.

- $3/in. to $4/in. pipe diameter/linear ft ($0.39/mm to 0.52/mm pipe diameter/m) of pipe if line and grade are not critical
- $4/in. to $6/in. pipe diameter/linear ft ($0.52/mm to 0.78/mm pipe diameter/m) of pipe if line and grade are critical
- $12/in. to $15/in. pipe diameter/linear ft ($1.60/mm to $2.00/mm pipe diameter/m) of pipe if line and grade are not critical for rock boring
- $20/in. to $25/in. pipe diameter/linear ft ($2.58/mm to $3.23/mm pipe diameter/m) of pipe if line and grade are critical for rock boring

4.14 SAFETY ISSUES

Safety on the jobsite is the responsibility of the contractor. Proper OSHA standards and manufacturers' safety and operations manual should be followed.

Part 5

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