WATER AGENCIES' STANDARDS

Design Guidelines for Water and Sewer Facilities

SECTION 12.2
TRENCHLESS CONSTRUCTION

12.2.1 PURPOSE

The purpose of this section is to provide guidelines for the use of trenchless construction in pipeline installations where standard open cut excavation methods are not feasible.

12.2.2 STANDARD TERMS AND DEFINITIONS

Wherever technical terms occur in these guidelines or in related documents, the intent and meaning shall be interpreted as described in the Standard Terms and Definitions.

12.2.3 GENERAL

Trenchless technology construction methods may be required for special crossings and conditions. Examples include:

A. The pipeline depth is excessive due to site conditions, making conventional excavation uneconomical when considering materials handling and shoring requirements.

B. Environmental conditions such as riparian habitat at stream crossings do not permit conventional construction.

C. Disturbance caused by conventional construction to suburban, urban, or business community is not permissible.

D. At congested intersections where from traffic or a utility standpoint, costly utility relocation, utility support/underpinning, or traffic control is avoided.

E. At high points in the pipeline due to hydraulic conditions.

Because of increased urbanization, utility networks are growing in size and complexity. As these networks grow, the need for special crossings by trenchless construction methods is becoming more popular due to their inherent advantages. Trenchless excavation construction methods may be divided into three basic categories: pipe jacking, conventional tunneling, and horizontal boring.

The direct costs of trenchless construction are more expensive than conventional cut-and-cover pipe construction. However, social costs, environmental impact, and other indirect costs due to noise, dust, loss of business, parking revenues, traffic delays, may make trenchless construction desirable. The District Engineer shall determine the proposed construction method for each project on a case-by-case basis and may prepare bid documents that allow prospective contractors to provide bid prices using both conventional and trenchless technology.

The following list of trenchless construction methods is not intended to be all encompassing, and is primarily intended for pipes in the 4-inch to 50-inch diameter range anticipated for water mains.

- Pipe Jacking
- Tunneling
- Horizontal Boring
  - Auger method
  - Micro tunneling
  - Slurry method
  - Directional drilling
  - Compaction/Pipe ramming
  - Percussive drilling

These categories are chosen for convenience. Many contractor and manufacturer innovations are occurring in this growing industry. Because of the nature of the industry, these categories are not necessarily discrete, but represent more or less a continuum of possibilities. Key to the success of these trenchless construction methods is defining the subsurface conditions; therefore each project is site-specific. Consequently, the Engineer should become familiar with possible construction methods and should refer to the latest information available within the industry. Included at the end of this section are some technical references as well as sources for additional information. However, the Engineer and geotechnical consultant should not provide direction as to the means and methods for construction, but specify performance requirements and limitations as required for the specific project (as set forth in the guideline specifications).

12.2.3 GUIDELINE

It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document. The Engineer may not deviate from the criteria presented in this section without prior written approval of the Agency.

A. Pipe Jacking

Pipe jacking according to some classifications is distinguished from horizontal boring in that pipe jacking allows for personnel entry to assist in performing the advance, whereas horizontal boring does not allow for personnel access. On the other hand, horizontal boring methods such as the auger method or microtunneling utilize hydraulic jacks similar to pipe jacking to advance the pipe, carrier pipe, or conductor casing. In essence, microtunneling and auger methods just have a more sophisticated method of advancing the pipe and removal of spoils. Regardless of the nomenclature, the minimum pipe diameter for conventional pipe jacking for personnel entry is about 30 inches for short distances and 6 feet for longer distances. Common sizes are 48 inches to 72 inches. Although there is no limit to the size of pipe that can be jacked, the largest is usually about 144 inches. Also, with all these pipe jacking methods, the Contractor must design the jacks to overcome the skin friction developed between the pipe and the surrounding ground.

Friction acting on steel pipe jacked through fills typically ranges from 100 to 600 psf of external surface area. Bentonite injected near the cutting edge of the pipe may reduce friction to about 100 psf. The development of special mud polymer lubricants has reduced the skin friction to about 25 to 50 psf where there has been a need. In many situations in firm soil, water alone is used as the lubricant. Because soil friction may increase with time, jacking operations should be uninterrupted. However, maintaining accurate line and grade and proper steering is as much as factor (if not more of a factor) of minimizing jacking forces as overcoming skin friction. After the pipe has been jacked, the lubricant may be replaced with grout.

For most situations, the practical limit for jacking is 1,000 to 1,200 feet. Intermediate jacking stations may be used; however, the shorter stroke length cuts the efficiency of the operations, thus increasing costs. Also, electric modifications, pumping considerations, laser limitations, hydraulic constraints, and reduced production make jacking long lengths uneconomical. Therefore, when long distances are involved, additional shafts should be considered. Alternatively, other methods such as tunneling or directional drilling require consideration.

Typically, the conductor casing or pipe is fitted with a simple cutting shoe or a small open shield to overcut the excavation and protect the leading edge of the pipe. During jacking in firm ground, soil materials are trimmed with care. The excavation face is also not advanced ahead of the jacking operation to minimize soil disturbance and loss of ground around the pipe. Some settlement can be expected, depending on the depth and diameter of the pipe.

Open shields have the advantage of accommodating the removal of cobbles, boulders, and obstructions. For larger diameter pipes above the groundwater table, where soils are susceptible to raveling, running, or sloughing, pipe jacking operations incorporate a shield with breasting tables and/or boards to minimize settlements. In firm ground, even wheel excavators are incorporated.

Spoil removal for conventional pipe jacking is by small muckers, rubber-tire low-profile load-haul-dump vehicles, rail, conveyor, or small cart. For smaller diameter pipes, slushers on pulleys have also been used.

B. Tunneling

Tunneling, like pipe jacking, implies personnel entry according to some classification systems. Unlike pipe jacking, curved alignments can be accomplished and excavation is feasible in hard rock. Also, the length of tunnel is not limited by the thrust of the pipe jacking rams.

As with pipe jacking, the means and methods of advancement and the initial support is the Contractor’s responsibility. The Engineer and geotechnical consultant are responsible for performance requirements and limitations applicable for each project.

Tunneling excavation and initial ground support methods are broadly classified into hard rock, soft/weak rock, and soils. The methods can be further subdivided under mechanized excavation or conventional excavation. Mechanical excavations may be by tunnel boring machines (TBM), shields, or mechanical excavators, of which there are a multitude of types. Conventional excavations may be by drill-and-blast construction or by hand construction, spaders, or other small equipment.

The smallest practical size for conventionally excavated tunnels is about 5-feet wide by 7-feet high, while for a circular shield or TBM excavated tunnel, the smallest practical diameter is about 4.5 to 6 feet, depending on the length of the tunnel. With the availability of used TBMs, drive lengths of less than 2-mile is competitive with conventionally driven small tunnels. TBMs also have the advantage of causing fewer disturbances to humans compared with drill-and-blast excavations when advancing through hard rock. While the guideline specifications provide for controlled blasting to limit peak particle velocities and damage to adjacent structures, the vibrations can disturb nearby residents. Where required, the Engineer should make a concerted effort and public outreach to educate affected parties about potential impacts. Nevertheless, unless there are special overriding considerations, as with all means and methods of trenchless construction, the Engineer should specify the use of either conventional or mechanized excavation. The marketplace, the Contractor’s experience, and the Contractor’s equipment dictate the methods.

Initial ground support depends on ground conditions. In hard rock, common support types are no support, patterned or random rock bolts and wire mesh, mine straps as required by ground conditions. In soft or weak rock, common support types include patterned or random rock bolts and wire mesh or mine straps as required; shotcrete; ribs and lagging; segmented concrete or steel liner; steel casing spilling and/or crown bars; and other combinations of these, as required by ground conditions. Soil requires similar initial support systems as for soft or weak rock; however, rock bolting methods and sparse support are generally not acceptable. The standard tunnel design practice is to not specify initial support unless incorporated into the final liner. Standard practice is for the Engineer to require submittal of the Contractor's tunnel work plan including initial support (to verify that the submittal meets industry standards without accepting responsibility for means and methods) under the category Review Submittal.

The conveyance of spoils depends on the excavation method but is typically performed by rubber-tire low-profile load haul dump vehicles, conveyors, or rail cars for the anticipated tunnel diameter.

After tunnel excavation is completed, the pipe is installed or placed on saddles, cradles, or rollers, and backfilled with cementitious materials such as grout or cellular concrete. Since in some situations, the diameter of the final pipe is small in comparison to the diameter of the tunnel, the Engineer should investigate any cost savings or other benefits to be derived using this corridor for other utilities. In very special circumstances, a utility corridor with access may be considered or even required.

C. Horizontal Boring

Horizontal boring is common in earth. Recently, horizontal boring methods have also been used in rock; however, there are practical limitations for rock. Horizontal boring methods are distinguished from pipe jacking and tunneling in that personnel do not enter the excavation. From this standpoint, horizontal boring methods would classically limit the diameter of such operations to less than about 30 inches. With the advent of computerized steering and guidance systems, horizontal boring by the non-personnel entry definition have encompassed projects up to 12.5 feet in diameter.

Horizontal boring techniques briefly described in the following paragraphs include: auger method, micro tunneling, slurry method, directional drilling, compaction/pipe ramming, and percussive drilling.

1. Auger Method

The auger method is a pipe jacking method in which removing spoils is accomplished by a continuous flight auger. The auger also transmits torque to the cutting head from the power source in the jacking/bore pit. The auger may be powered pneumatically, hydraulically, or by an internal combustion engine through a mechanical gearbox. Similar to conventional pipe jacking, the leading edge of the pipe is typically equipped with a cutting shoe. Bentonite is also used to lubricate the pipe and minimize sloughing. The Contractor must carefully monitor the position of the casing and the advance of the auger and cutting head to minimize the risk of unsupported excavated ground and potential settlements.

A steering apparatus attached to the outside of the casing at the cutting head and a water level sensing device for vertical control is commonly used to make minor grade adjustments. The horizontal alignment can be corrected to a minor amount on larger casings by withdrawing the augers and sending personnel through the casing to the leading edge to manually excavate and install wedges on the appropriate side. Water lines are sometimes added behind the steering head to facilitate spoil removal.

The horizontal boring equipment is commonly mounted on a track, but in some applications where large rights-of-ways are available, it is supported by a cradle suspended from a crane. Cradle-type horizontal boring operations are commonly referred to as “side boom” or “swinging” methods. Consequently, the jacking/bore pit construction is not as critical as for a conventional pit, since all preparatory work is done outside the pit and no workers are permitted to enter the pit. No foundation or thrust reaction structures are required; however, a jacking lug or deadman is installed at the bore entrance. Water level and steering apparatus systems for track-type horizontal boring is not appropriate for the cradle-type method. Cradle-type operations require pressurized steering systems. In urban and suburban areas, cradle-type operations are not feasible. Also, water utility lines tend to run parallel to roads and then turn, and large right-of-ways are not available.

2. *Micro tunneling*

Micro tunneling machines have taken sophisticated, hydraulically operated, and automated soft-ground tunnel boring machines such as slurry tunneling machines and scaled them down for diameters as small as 8 inches for excavation and spoil removal. Micro tunneling, as with horizontal boring, in some classification systems, has evolved to encompass non-personnel entry of pipe jacking operations for which the record is about 12.5 feet in diameter. Micro tunneling is considered a misnomer by some and is simply pipe jacking with an automated miniature tunnel boring machine ahead of the jacked pipe.

With the numerous manufacturers of micro tunneling machines worldwide and the advent of trenchless construction, micro tunneling is particularly advantageous for difficult ground conditions without the use of expensive dewatering systems or compressed air. Micro tunneling also has extremely accurate alignment tolerances for long drives, making conventional horizontal boring and pipe jacking competitive for only the best of soil conditions and the shorter drives. Although most of the micro tunneling equipment is designed to operate in soft ground soil conditions, there has been an increased demand for micro tunneling machines which can also excavate soft/weak rock and even hard rock (within certain limitations).

Soft-ground micro tunneling machines use the principle of “earth-pressure balance” TBMs in which the pressure applied to the cutting face equals the pressure from the ground against the cutting face, thereby providing full face control and preventing loss of ground and settlement. Some machines use pressurized water to assist in excavation. In competent firm ground this may be acceptable; however, in loose, running, or flowing ground, the principle of earth-pressure balance is not achieved and can lead to unacceptable settlements.

Because micro tunneling machines are jacked, they have the same limitations with respect to jacking distances (1,000 to 1,200 feet) and curves as for pipe jacking.

Cobbles and boulders can make excavation difficult if not planned. Micro tunneling machines can handle boulders and obstructions typically 1/5 to 1/3 of the diameter of the cutter head depending on the type of cutter head. To handle coarse-grained materials, micro tunneling machines are typically equipped with eccentric cone-type crushers, jaw crushers, strawberry cutters (button bit carbide inserts), or multidisc kerf-type cutters with carbide inserts to break up cobbles/boulders prior to ingestion behind the cutter head. The cutter head is also armored with hard facing.

For the smaller diameter machines (less than about 4.5 to 6 feet), minidisc cutters 6 inches in diameter have been employed for short drives in hard rock. These disc cutters if worn cannot be replaced without removing the entire machine or installing a rescue shaft. The small bearing areas of minidisc cutters have experienced problems with their mounts and bearings in the past.

Torque is applied through an auger and thrust through the casing. The life of the cutter depends on the hardness and abrasiveness of the rock. The longest successful mini-hard rock TBM drive is less than 300 feet. The smallest diameter is about 24 inches. Although this technology is evolving and improvements are being made, where longer drives are anticipated in hard rock, the Engineer should consider conventional tunneling. Moreover, means and methods are the responsibility of the Contractor.

Spoil removal for soft-ground micro tunneling machines is typically by slurry using smaller slurry conveyance pipes and pumps as required. Another method is by auger similar to the horizontal boring auger, only a bentonite slurry is also injected at the cutter head and conveyed by the augers to a holding tank (volume equal to one-shove) beneath the thrust jacks in the pit.

Spoil removal and rotation of cutter head is accomplished by an auger for hard rock mini-TBMs (less than about 4.5 feet).

3. Slurry Rotary Drilling (SRD)

This method of horizontal boring is similar to the auger method in that it is typically executed using boring and receiving pits and is intended for straight line boring. However, a drill bit and tubing are used rather than a cutting head and auger. Drilling action is accomplished by rotating and pushing the drill tubing. A drilling fluid is also used which can be water, air, or bentonite slurry. The drilling fluid keeps the rotating bit clean and aids in spoil removal. Drilling fluid is delivered through the drill tubing and spoils return to the boring pit through the bore hole. In unconsolidated, noncohesive soils, bentonite slurry aids in preventing bore hole collapse and much of the slurry cuttings remain in the bore hole. Pilot holes are typically drilled first, then reaming bits are employed to enlarge the bore for the desired carrier pipe diameter. The drill bits are not directionally controlled and intermediate access pits are sometimes employed to ensure proper alignment of the bore path. Since the bit is unguided, the accuracy of the bore hole depends largely on subsurface conditions. Obstacles can deflect the drill bit off course, and operator experience plays a significant role in the bore’s success and accuracy.

This method is most effective for bore holes from 2 to 12 inches in diameter; however, 48-inch bores have been successfully completed in stable soil conditions. Pipe installation is independent of the boring operation and thus any pipe material that is suitable for jacking or pulling can be installed. Installing pipe spans in the range of 40 to 75 linear feet is most common with this method. As pipe spans increase, so does the chance of unacceptably aligned bore holes due to the unguided nature of this method.

4. Directional Drilling

Many innovative features from the oil drilling industry have been applied to horizontal earth boring and have advantages over SRD. The terms horizontal directional drilling and directional boring apply to a wide range of techniques and applications. Two key features of directional drilling differentiate it from SRD. The first is that a drill motor powered by pressurized cutting fluid operates the drill bit rather than a rotating drill string. The second is that the drill bit is steerable and thus can be maneuvered around obstacles or to correct the bore path. These characteristics give directional drilling superior capabilities and wider applicability over SRD. Thus, it is the more common method of the two employed.

The steering ability of directional drilling results from the chisel shape of drill bits used which deflects it in the direction oriented. When the bit rotates, it progresses straight. Controlling rotating and push allows for drill bit steering. Drill string position is accomplished with a guidance system mounted in the drill bit assembly, and by magnetically tracking it from the ground surface above the bore. For hard rocks and boulders, a rotary percussion cutterhead can be used.

Once a pilot hole is excavated, larger diameter bores are created by pulling back a large diameter cutter with the drill string (back reaming). The hole may be back reamed in a succession of increasingly larger diameters to achieve the desired final diameter. Special back reamers are available for hard rock or gravels. On the final back reaming, the finished desired pipe is pulled through. The use of directional drilling is particularly advantageous for river crossings.

Large percentages of gravels, cobbles, and boulders make drilling difficult and expensive. Steering accuracy is also an important consideration.

5. *Compaction/Pipe Ramming*

Impact moles or pipe ramming techniques, as the names imply, use a pneumatic system which punches through soil by a percussive action. The driving head is typically cone shaped using a stepped cutting head or a series of open steel tubes which punch through the ground, and is subsequently blown through, flushed free or emptied by reamers.

Another technique is to drive the pipe or casing directly without a cutting head. If the line is 6 inches in diameter or greater, the head is driven with an open face, with a band installed around the leading edge for reinforcement. This also reduces the friction from the following pipe. In some cases, water or bentonite slurry can be applied to the outside of the pipe for lubrication.

Diameters obtainable by pipe ramming vary from less than 2 inches to as much as 4.6 feet. Smaller diameter bores (less than 7 inches) are common in the United States while Europe and Japan have had great success with larger diameter impact moles.

Larger diameter pipe ramming can accommodate cobbles and boulders since there is no equipment is inside the casing for obstruction of these obstacles. Pipe ramming techniques used to install a smaller diameter pipe may not offer the same amount of flexibility in excavation.

Pipe ramming is worth considering because it is reported to save time and money in equipment and labor time compared with pipe jacking or other microtunneling techniques.

6. *Percussive Drilling*

Combining percussion action with rotary drilling has proven to be an effective means of drilling through hard rock and has been applied in some trenchless methods. Applying a down-the-hole (DTH) percussive drill in conjunction with a track-type auger set up has been used to horizontally bore through hard rock. The largest DTH bit available is 43 inches in diameter and is reported to have been applied in lengths in excess of 1000 feet.

DTH hole percussive bits are pneumatically powered for percussion energy, and rotation and thrust are supplied by the drill rig. Hole cuttings are removed by the air supplied to the bit and are guided back to the bore pit in the annulus between the drilling shaft and the casing. Drilling hammer accuracy improves with harder ground conditions. This method is non-steerable and thus initial setup and alignment are critical to boring to the receiving pits. Large diameter bores are typically accomplished by drilling a small pilot hole and then opening the hole with larger bits in subsequent passes. The limitations of this method are the environmental impact during initial startup due to the percussive impact at the surface and dust control from cuttings blown out by the compressor throughout the operations.

D. Jacking Pit

Minimum size jacking pits depend on the size of the pipe being installed. For the 20-inch to 50-inch diameter range, the minimum width for jacking pits range from about 8 feet to 15 feet, and the minimum length will vary from about 20 to 40 feet, depending on equipment and pipe length. Minimum size receiving pits will vary from about 6-foot to 10-foot diameter.

With directional drilling, a jacking it is not necessarily required. With any trenchless method, however, a small staging area is required adjacent to the work area and is typically a minimum of 5,000 square feet.

Although the Contractor is responsible for these items, the Engineer and its geotechnical sub-consultants should provide geotechnical criteria that enable the Contractor to design the shoring and foundation for its equipment. Also, the Engineer should consider the Contractor's staging requirements and need for jacking and receiving pits when planning special crossings.

12.2.5 MATERIAL SELECTION

With all these trenchless scenarios, a carrier pipe or conductor casing is jacked or pulled for installation. Typical pipe is reinforced concrete pipe, plastic pipe, corrugated metal pipe, or sheet steel pipe in 10-foot to 20-foot sections. Crossings under county or state highways may require a steel or other type of conductor casing like reinforced concrete, or plastic. The carrier pipe is installed on saddles (by rollers, cradles, or slurry) which are later backfilled with cementitious materials such as grout or cellular concrete. Smaller diameter pipes are not usually grouted.

Alternative one-pass liners with a sacrificial steel liner cast with an internal steel liner have also been manufactured in the past. Other one-pass linings for potable water pipes are available. These specially coated linings have a sacrificial layer in addition to normal corrosion protection. They are patented and offer a flush bell with an interlocking joint that seals pressures to greater than 300 psi.

Directionally drilled one-pass lining installations use welded steel pipe, also with a sacrificial coating for installation.

Trenchless constructed pipes may have special transition pipelines or vaults required on either side of the bored subsurface crossing.

12.2.6 REFERENCE

A. Should the reader have any suggestions or questions concerning the material in this section, contact one of the member agencies listed.

B. The publications listed below form a part of this section to the extent referenced and are referred to in the text by the basic designation only. Reference shall be made to the latest edition of said publications unless otherwise called for. The following list of publications, as directly referenced within the body of this document, has been provided for the user's convenience. It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document.

Substantial material (e.g., manuals, guidelines, videos, and references and associations) has been published about trenchless construction. The American Society of Civil Engineers has a draft "Standard Construction Guidelines for Microtunneling" (November 1998) that is under committee review. The following are a few sources provided to the Design Engineer as a primer and introduction to trenchless construction references.

- Boyce, G.M, and Cross, T.R., 1997, A 10-year review of microtunneling in North America, in J.E. Carlson and T.H. Budd, eds., Proceedings of the Rapid Excavation and Tunneling Conference, Society of Mining Engineers, Las Vegas, NV, June, 22-25.

- Hancher, D.E., White, T.D., Iseley, D.T., 1989, Construction specifications for highway projects requiring horizontal earth boring and/or pipe jacking techniques, Joint Highway Research Project No: C-36-672, File 9-11-26, Conducted for Indiana Department of Highways for Purdue University.

- Iseley, D.T., 1990, Trenchless excavation construction: microtunneling the United States experience, in R. Sinha, ed., Proceedings of the International Symposium on Unique Underground Structures, Colorado School of Mines and U.S. Bureau of Reclamation, Denver, Vol. 2, Chap 92, June.

- TRB (Transportation Research Board), 1997, Synthesis of Highway Practice, 242, Trenchless Installation of Conduits beneath roadways, National Cooperative Highway Research Program, Iseley D.T., and S.B. Gokhale, eds., National Academy Press, 76p.

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