The Importance of Geologic Information Required for Trenchless Technology-The Role and Responsibilities of the Engineering Geologist

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Abstract

Trenchless technology denotes the equipment, supplies, and methods used for the installation, replacement, or renewal of subsurface pipe without the primary use of a trench. Trenchless technology minimizes surface disturbance associated with utility installations. The use of trenchless methods of utility installation, replacement or renewal decreases installation costs in the long term. Methods of pipe installation, pipe replacement, pipeline renewal and pipeline inspection have been greatly improved in the last ten years. This allows trenchless methods of pipe installation, such as horizontal directional drilling (HDD), to be competitive with open-cut installation. It should be emphasized that the use of trenchless technology drastically reduces or eliminates the possibility of trench accidents that annually cause injury and deaths in the United States.

Importance of Geologic Data to Trenchless Design and Installation

Most geologists are unfamiliar with these methods, the technology used, and the need for geologic input in the design process that precedes new installations. One method of trenchless utility upgrade, pipe bursting, requires geologic information for an upgrade to be successful. If pipe bursting is attempted where the original installation is made in a rock trench, the pipe burst may be impossible, or pressures may cause surface heaving. Geologic information may also be required for pipe relining if a structural pipe liner is used. The overlying weight of the soil on the utility product pipe should be known so that a pipe liner may be chosen of sufficient strength to perform the upgrade. Knowledge of soil conditions may also affect manhole renewal, and is essential for upgrade by pipe reaming.

The importance of geologic and soils map relationships used to plan a proposed utility installation's alignment cannot be understated. Normally, three parameters are considered in advance of an installation: the depth of the crossing to be made, the length of the crossing, and the type of pipe to be used. If critical information is not interpreted correctly or ignored, problems may lead to cost overrun, or even termination of a boring. This information is essential for the owner to insure a successful boring and for the contractor to realize profit from the bore. A fourth parameter should also be considered: the type(s) of geology and soil(s) present in the path of the crossing, including the degree to which a soil varies between entry and exit. Knowing the geology prior to installation allows selecting tooling and method choices to decrease bid price. Issues of soil reactivity with certain types of pipes may also be addressed in advance, enabling the most suitable pipe to be chosen for an installation.

Trenchless Technology – An Introduction

Trenchless, or "no-dig" technology is used to avoid the social costs of open-cut underground utility installation/renewal, and where trenching is uneconomical or impossible. Despite additional short-term costs for some methods, trenchless installations are competitive when social costs are considered. Table I lists these social costs, which are problems that may be prevented by the use of trenchless methods (Najafi, 2004.)

Trenchless technology may be categorized into two areas: new installations and renewals. New installations use some form of horizontal boring. Renewals include pipe bursting and slip lining, manhole repairs and rehabilitation among others. Methods of trenchless technology that do not require the use of a trench at all for an entry or exit from the pipe may be referred to as 'pure' trenchless. Other methods do require some trenched access, but this is minor in comparison to the overall length of installation or repair. Geological information is always useful in advance of a new installation. Geologic input is also critical for the renewal upgrade method of pipe bursting. Trenchless installations are normally concerned with the basic equipment selection parameters *of: the depth of the crossing or renewal,* the length of the crossing or renewal, and the type of utility product pipe or repair that is used.

Assessment and analysis of the depth of an overall crossing or renewal depends upon the overburden weight of the soil, and the level of permanent groundwater, and whether that level fluctuates. The maximum possible length of a crossing depends on the type of materials to be encountered. Finally, the type of geomaterials present can directly influence the choice of utility product pipe that is put into service. Depth to rock is additional critical consideration in both choices of method and type of tooling, among others. Looking at the individual methods of horizontal boring and the possible geology they may encounter allows a designer to choose the type of boring best suited for an installation.

Methods of Horizontal Boring

Horizontal borings have been used for the successful installation of utility pipe for over a hundred years. The earliest installations were accomplished by hand tunneling. Methods used and precautions taken were comparable to those used in the mining industry at that time. Today, there are seven types of horizontal boring that are recognized by the trenchless technology community. Choosing a boring method is usually based on three criteria: the length of the crossing to be made, the depth of the crossing to be made, and the type of utility product pipe to be installed. It can successfully be argued that the type of soil and/or rock to be encountered in the bore path is an additional criterion that should be considered in this group.

Horizontal borings are classified according to their ability to steer along a curved line, whether or not they require human entry, and by their method of excavation or advance. Particular types of borings are used in different ground conditions relative to the percentage (and size) of coarse fragments in the bore path, and by the location of groundwater relative to the bore. Certain conditions make some types of horizontal boring impossible, while other conditions preclude the use of horizontal borings altogether.

Social Cost Category	Description of Potential Problems in Open-cut Construction
Vehicular and Traffic Disruption	With open-cut construction, the public pays for the increased time spent in traffic delays, and by the use of detours. Costs include added fuel costs, additional motor vehicle maintenance and repair.
Road and Pavement Damage	Open cut installation increases the roughness of a pavement's surface after repair, and may lead to structural failures. Poor restoration may lead to repeated repairs. Differential settlement, poor backfilling, patching, and successive utility cuts aggravate overall problems.
Damage to Adjacent Structures	Dewatering, excessive excavation, improper techniques in shoring and underpinning may cause uneven settlements and distress to structures as a result of open-cut underground utility construction.
Noise and Vibration	Vibrations and noise may lead to inconvenience and citizen complaints. These are more frequent in open-cut installation.
Air Pollution	Open-cut installations in dry periods may lead to excessive dust; heavy construction equipment uses more fuel and generates excess Cox, Nox, and hydrocarbon gases. All are of special concern in areas of close proximity to schools and hospitals.
Pedestrian Safety	Diversion of traffic onto residential streets increases hazards to pedestrians; open cuts are also safety hazards to pedestrians, especially children and the elderly.
Business and Trade Losses	Customers avoid open-cut construction areas that causing business and trade losses. These are matched by the concomitant decrease in government revenue from taxes on gross receipts and parking meters in areas with metered parking.
Damages to Road Detours	Detours caused by open-cut construction increase loads on the detour road, which may not be designed to accept heavy motor vehicle traffic. This decreases road lifespan and may lead to further damage.
Site and Public Safety	On-site accidents to construction workers and the general public increase in areas of open-cut construction.
Citizen Complaints	Disruptions to the normal flow of life caused by open-cut construction increase the frequency and magnitude of citizen complaints.
Environmental Impacts	Open-cut construction may permanently alter or damage sensitive affected areas such as rivers, streams, natural habitats, public parks, protected natural areas, wetlands, historic districts and buildings, etc.

Table 1.
Social Costs of Open-Cut Construction
(Adapted from Najafi, 2004)

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Furthermore, it can be stated that the phrase "horizontal bore" means different things to different users. To be accurate in describing a horizontal boring, a geologist or engineer should denote the type of horizontal boring. There are seven basic types of horizontal boring:

1) Auger Boring – The auger boring process employs simultaneously jacked steel casing while spoil is removed inside the casing using rotating continuous flight augers. Spoils are transported back to the entry point or bore pit where they are removed.

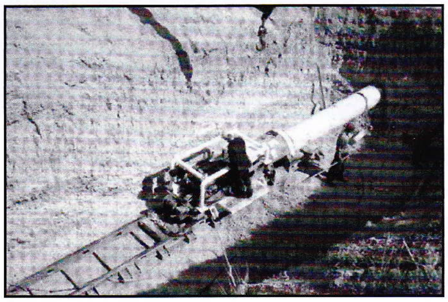


Figure 1. Example of Auger Boring. Photo courtesy of Barbco, Inc.

2) Pipe Ramming – In Pipe ramming, an enclosed hydraulic ram repeatedly strikes the end of a pipe to advance it through the soil. The pipe can either be rammed closed-ended or open-ended. The use of a jacking frame is not required as the pipe is connected directly to the pipe ram.

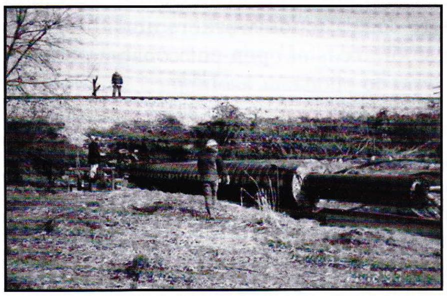


Figure 2. Example of pipe ramming. Photo courtesy of Hammerhead Mole, Inc.

3) Pipe Jacking – Though 'pipe jacking' can be applied to the process of hydraulically advancing pipe with the use of a jacking frame, this process requires man-entry for spoil removal during the hydraulic advance of the pipe.

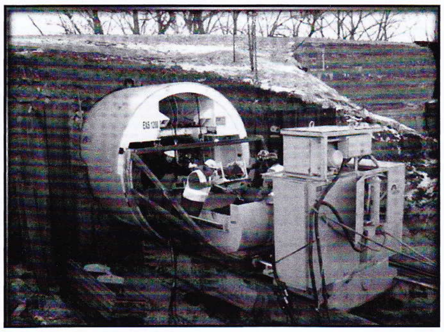


Figure 3. Example of Pipe Jacking. Photo courtesy of Akkerman, Inc.

4) Horizontal Directional Drilling (HDD) – Horizontal directional drilling is a two-stage process in which a pilot bore is drilled along a predetermined path, followed by the installation of utility pipe as the hole is enlarged by backreaming with a larger bit.

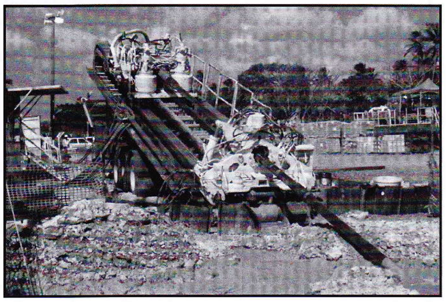


Figure 4. Example of large-scale horizontal directional drilling. Drill rigs of this size are normally used for long (>2000') crossings, Including major river crossings. Photo courtesy of American Augers.

5) Small-diameter displacement or compaction tools – Simplest of all horizontal boring methods, their use is limited to small pipe installation. There are three predominant methods used, the push rod method, the rotary rod method, and the percussion method which uses an impact tool, or "missile mole". These are the most inaccurate of all horizontal boring methods.

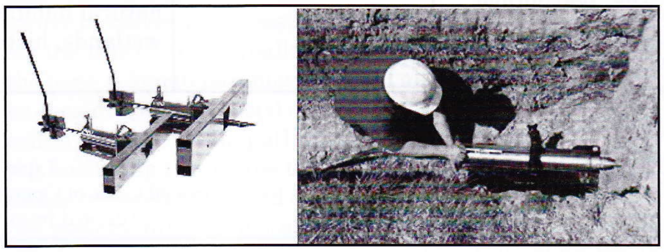


Figure 5. Examples of rod-pushing tools on left and impact impact tool on right. The upper rod-pushing tools also rotates, so it can be considered to be a rotary rod tool. Photos courtesy of Charles Machine Works, Inc. (Ditch Witch)

6) Microtunneling- Micro-tunneling is a highly accurate method of installing pipe using a jacking frame without man-entry, and is remotely controlled and targeted using a laser and theodolite. It is extremely useful below groundwater levels because it provides continuous support to the tunneling face, which pipejacking does not.

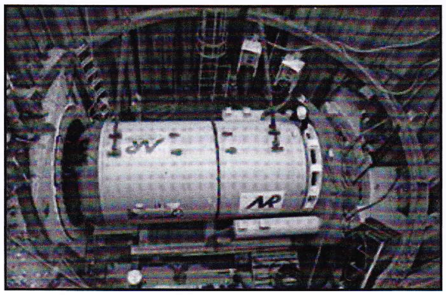


Figure 6. Example of microtunneling boring machine. Photo courtesy of Robbins, Inc.

7) Pilot tube microtunneling – This is a relatively new, highly accurate method of installation, that installs a product pipe to line and grade by use of a pilot tube followed by upsizing and additional soil removal to install the product pipe. Continuous flight augers are used to transport soil spoil, and a guidance system is used which involves a laser and a camera-mounted theodolite.

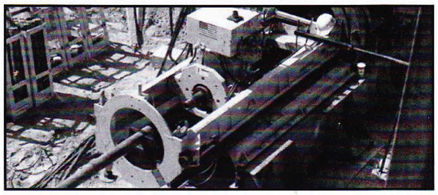


Figure 7. Example of pilot-tube microtunneling machine. Photo courtesy of Akkerman, Inc.

Each of these horizontal boring methods performs best with accurate advance geotechnical information. For small-diameter displacement or compaction tools, the least amount of information is required, since these are relatively simple and robust.

Microtunneling should have the most comprehensive geotechnical information available, to minimize the chance of unexpected obstacles requiring a time-consuming (and quite costly) change of cutter head or even a rescue attempt. A summary of the types of horizontal boring mentioned, along with their suitability for various ground types is shown in Table 2.

Geologic variability necessitates a site visit prior to boring. Ground conditions

Ground Conditions	Auger Boring	Micro-Tunneling	Pipe Ramming	Methods of Soil Compaction	Pipe Jacking	Horizontal Directional Drilling (HDD)	Pilot Tube Micro-tunneling
Soft to very soft clays, silts and organic deposits.	Y	Y to M	Y	N	M	Y	M
Medium to very stiff clays and silts.	Y	Y	Y	Y	Y	Y	Y
Hard clays and highly weathered shales; coals.	Y	Y	M	M	Y	Y	Y
Very loose to loose sands; **Above the water table**	M	Y	Y	M	Y	Y	M
Medium to dense sands; **Below the water table**	Y	Y	Y	M	Y	Y	Y
Gravel and Cobbles 50-100mm (2-4") in diameter	Y	Y	Y	M	Y	M	Y
Soils with significant cobbles, boulders, and obstructions larger than 100-150 mm (4-6")	M	M	Y	M	M	M to N	M
Weathered rocks, weatered shales, and well-consolidated soils such as glacial till.	Y	Y	M	M	M	Y	M
Slightly weathered and unweathered rock	Y	Y	M	N	N	M	N

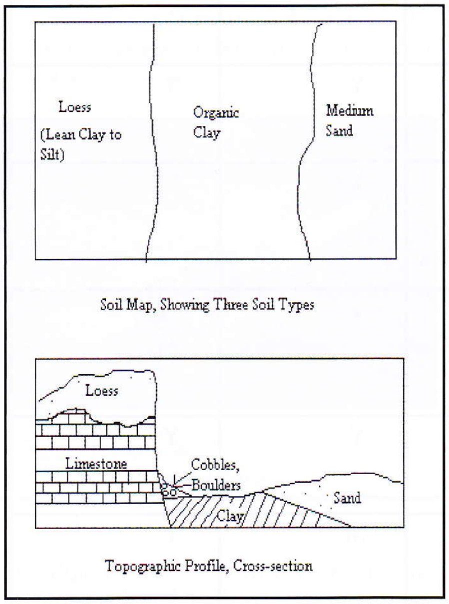
Table 2 Suitability of Ground Conditions for Various Horizontal Boring Conditions (Table adapted for use from Iseley, D.T. et al., Trenchless Construction Methods and Soil Compatibility Manual, 3rd ed.)

Y = Yes – Method is suitable when performed by an experienced contractor with suitable equipment.

M = Marginal – Difficulties may occur for the contractor, some modifications of equipment or procedure may be required to successfully complete the bore.

N = No – This method is generally not useful under these conditions. Substantial problems will occur, and the method is not suited for and the equipment is unintended for the conditions present.

may be known to some degree, but geologic and soils mapping may not indicate the real materials underlying a crossing. Soils mapping may not indicate of the nature of, or the depth an underlying bedrock contact. Regional geologic mapping is normally on a topographic base, but it suffers from the inability to predict the types and the degree of variability of individual units that a localized map offers. A common example of potential misinterpretation from Missouri is depicted in Figure 1.



Soil Map, Showing Three Soil Types

Topographic Profile, Cross-section

Figure 1. Possible soils map and constructed profile from Missouri illustrating potential types of misinterpretation possible in trenchless installation for contractor. Note differences between map view and cross section. (from Davis, 2007)

The upper part of the figure is a possible depiction on a soils map of an area. Normally it would be superimposed on an aerial photograph. Interpreting the soils map as three differing types of soils in the path of a horizontal directionally drilled installation, a contractor would bring soil boring tools, and possibly a smaller capacity rig to address what he might consider to be soft soil ground conditions.

The cross-section below the soil map illustrates the reality of the contractor's predicament. Instead of bringing just soil tools on the HDD rig, the contractor should have rock tooling, perhaps even a larger thrust capacity rig, and even a down hole mud motor for cutting rock. His drilling fluid volume needs will be altered significantly by the gravel and cobbles at the base of the cliff, or he might need a pipe ram to drive a guide casing for his HDD tooling through these coarse fragments. Finally he may need to change his overall drilling fluid composition depending upon the depth at which he crosses the sand and clay.

Inaccurate interpretation of completed mapping is one difficulty that is often encountered in determination of an area's suitability for a particular trenchless method. Another difficulty in geologic determination of the suitability of ground for the use of a trenchless method is the use or reliance on out-of-date or inaccurate mapping. One example pertains to Missouri, which is depicted on the map in Figure 2 as having no clays with shrink-swell potential. This map, from a Federal Highway Administration publication published in 1976, is inaccurate. Many soils in northern Missouri are composed of highly altered glacial loess, especially in the central northern part of the state. Clays of this region are montmorillonitic, with total clay sometimes higher than 70%. These overconsolidated clays also have a tendency to swell when in contact with drilling fluids, and actually can swell a borehole shut or make it difficult or nearly impossible to install pipe without additives in the drilling fluid.

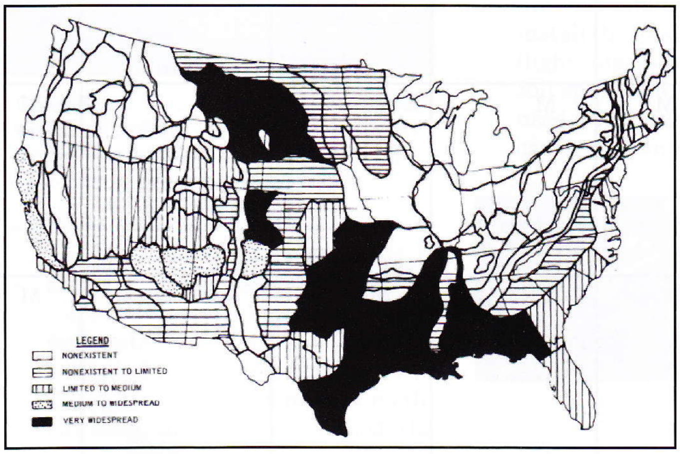


Figure 2. Frequency of occurrence of high-volume change soils in the United States- example of an inaccurate map from the Federal Highway Administration. (from Patrick and Snethen, 1976)

Pipe Bursting

With the expiration of the British Gas patent for the process of pipe bursting in 2005, many utilities and contractors welcomed the opportunity to replace and upgrade existing water, sewer, and natural gas pipeline system elements by the process of pipe bursting. In some circumstances, such as manhole-to-manhole upgrades, pipe bursting can be considered a 'pure' trenchless technological upgrade or renewal without need for any excavated access. Pipe is broken by brittle fracture, supplied by a mechanically applied force from within the original pipe. As the original pipe is broken and the fragments of the pipe are forced into the surrounding soil, the replacement/upgrade utility pipe is pulled into place. A conically shaped tool (bursting head) is used to break apart brittle pipe, or cutting heads are used to break ductile iron and thinner steel pipe. The original composition of the in-place pipe determines the type of tooling used to break the pipe, but the geology determines the overall ability of the system to do the bursting job, whether drilling fluids are required, and if soil will heave above the newly installed pipe, damaging aboveground facilities.

One patented method used to prevent above-ground damage and damage to adjacent utilities is a method developed by John Nowak of Goddard, Kansas. This method, known as the InneReam$_{TM}$ method, uses a horizontal directional drill to remove the original utility pipe prior to a new pipe being pulled into place on the same pass. This method is highly preferred where the original utility was installed in a rock trench specially cut for the underground installation of utilities. Figure 3 illustrates a standard bursting configuration with a bursting head followed by the utility product pipe ready for installation. Figure 4 illustrates the advantage of the Nowak InneReamTM method in a rock trench, a method also known as 'pipe reaming' (Nowak, 2005).

The Geologist in Trenchless Installations – Investigator and On-Site Troubleshooter

The geologist plays a key role in the overall success of a trenchless project. A geotechnical investigation of a planned pipeline installation or replacement route is justified to insure success. There are many potential geotechnical hazards and normal soil and rock characteristics to consider for the installation that can be addressed by a well-planned investigation.

The length of the installation, the depth of the installation, and the type of product pipe installed control pipeline installation. These three controls should also be addressed by the geotechnical investigation. If in a 'difficult' soil or rock, the possible length of the installation will be decreased. Weight of the overlying soil on an installed pipe is important so the possible depth at which the pipe can be installed can be determined. Issues of soil reactivity may affect some pipes, such as concrete or steel, and cause corrosion that can be accelerated in some soils with high conductivity. Investigating the planned route of a utility product pipe can be a challenging yet rewarding task as many different possible alternatives emerge, and potential geologic challenges to successful installation by trenchless methods are examined.

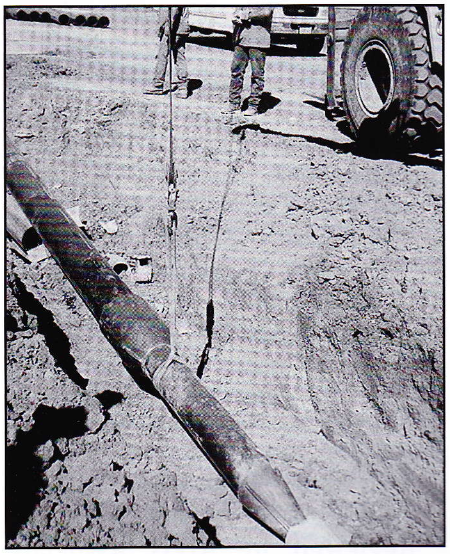


Figure 3. Bursting tool prior to pull-through. Note that the bursting head is at the bottom of the photograph, and that the pipe to be installed follows the bursting head. The pipe will be installed simultaneously with the pipe being burst into the surrounding soil. Photograph courtesy of TT Technologies, Inc.

The types of information to be gathered by a geotechnical investigation of a utility product pipe route vary depending upon the needs of the particular type of horizontal boring chosen for use. For instance, if a steel pipe of 36 inches diameter needs to be installed under an obstacle (such as a railroad track which cannot be closed due to traffic) with an approximate length of 125 feet, auger boring and pipe ramming are two methods which can be chosen for use, because both can be used with (in fact, require the use of) steel pipe. During the geotechnical investigation it is determined that the fill embankment through which the pipe is to be driven is largely composed of boulders with an average size of 18 inches. This determines that auger boring should not be used for the installation, since the average size of boulders in the path of the intended pipe installation are larger than that which can be transported back as spoil by the augers that are used. Pipe ramming, on the other hand, would either break the boulders with the reinforced steel leading edge band on the lead pipe segment, or it would swallow them whole, to be removed as spoil with compressed air at the end of the ram.

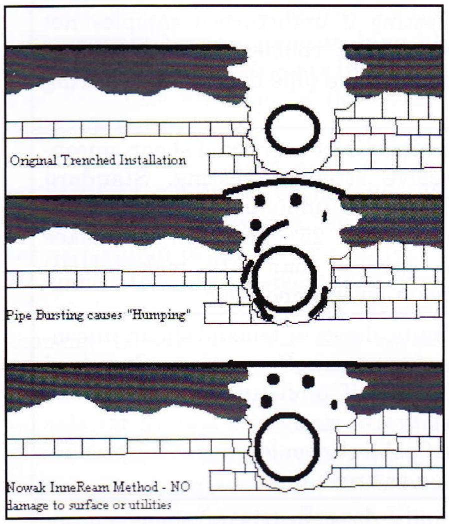


Figure 4. Advantage of the Nowak InneReamTM method of pipe reaming over bursting in a shallow rock trench original excavation.

The amount of geotechnical information that needs to be obtained prior to a project varies with the length of the installation, the depth of the installation, and the complexity of the geology that might be encountered. Longer installations even in simple geology need verification that the geology remains simple over the stretch of the job. Deeper installations require deeper geotechnical borings to verify the local ground conditions. Geotechnical information bears directly on the choice of pipe for an installation (for instance, angular chert fragments in the soil can slice thin-walled polyethylene pipe and render it unusable) and any special coating or thickness requirements that are needed for installation.

Without accurate advance geotechnical information, unknown conditions may affect an installation and make it difficult or even impossible. For example, boulders greater than one-third the size of an auger boring make that method extremely difficult or impossible, since the augers must be able to transport spoil down their length for removal.

Table 3 is a good summary of the types of geotechnical laboratory testing that should accompany borings in a pipeline alignment. For instance, if a designer chooses pilot tube microtunneling for an installation and boulders are found in the chosen alignment for the installation, another method should be chosen based on the difficult geology present.

The geologist on a directional bore or trenchless installation site should be a troubleshooter, preventing difficulties with accurate knowledge of soil conditions on the site.

There are no publications that deal primarily with trenchless installation from a geologist's perspective. Geologists should prepare themselves for this rapidly expanding field of utility installation by learning as much about the ground conditions that affect the installation process and some of the basics of soil-pipe interaction. There are several excellent textbooks that serve as an introduction to the field of trenchless technology, geared to a construction management and civil engineering audience, available for purchase online and listed in the references for this paper. The National Utility Contractors Association (NUCA) also produces a paperback text that addresses soil considerations in trenchless technology, also listed in the references. NUCA's text (Iseley et al, 1999) serves as an excellent first reference in soil and rock investigation for utility product pipe installation.

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Type of Trenchless Installation	Geotechnical Characterizations Recommended
Methods of Soil Compaction	Atterberg limits for soil. Method best suited for stiff clays that are cobble and boulder-free. Presence of cobbles and boulders can cause deflection from intended bore path.
Pipe Jacking	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. Boulders can cause pipe deflection leading to edge loading.
Pipe Ramming	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. Pipe ram will break up and swallow boulders or cobbles. Need to know soil type to mix bentonite lubricant.
Microtunneling	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available.
Auger Boring	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. Presence of cobbles/boulders greater than 1/3 diameter of the pipe makes auger boring impossible.
Horizontal Directional Drilling (HDD)	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. Greater than 25% gravel in soil makes HDD difficult, greater than 50% makes HDD extremely difficult, even impossible.
Pilot Tube Microtunneling	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. Best to use method in lean or fat clay soils, also silts. Cobbles or boulders can stop product pipe installation or break pipe.
Pipe Bursting	Atterberg limits, direct or triaxial shear, unconfined compressive strength testing. Standard Penetration Testing if undisturbed samples not available. The stiffer the soil, the more difficult the installation.

Table 3.
Basic Recommendations for Geotechnical Characterization for Trenchless Installation.

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References

Davis, George H., 2007. "The Politics of Scale – Geological Quadrangle Mapping for Trenchless Suitability Assessment in an Urban Area", *Proceedings of the 2007 Underground Construction Technology Conference and Exhibition,* Houston, TX. On CD-ROM. Oildom Publishing Company.

Najafi, Mohammed (ed.), 2006. *Pipe Bursting Projects – ASCE Manual and Reports on Engineering Practice No.112.* American Society of Civil Engineers. 96 pg.

Iseley, D. T. M. Najafi, and R. Tanwani, Editors. (1999). *Trenchless Construction Methods And Soil Compatibility Manual.* 3rd ed. Arlington, Virginia: The National Utility Contractors Association (NUCA).

Najafi, Mohammed, 2004. *Trenchless Technology – Pipeline and Utility Design Construction, and Renewal.* McGraw- Hill. 489 pg.

Nowak , John, 2005. Personal communication.

Patrick, D.M., and Snethen, D.R., 1976. *An Occurrence and Distribution Survey of Expansive Materials in the United States by Physiographic Areas.* United States Federal Highway Publication FHWA-RD-76-82, Interim Report. 68 pg.

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