Trenchless Technology – An Overview

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Abstract

This paper presents an overview of the trenchless technology methods; trechless projectsand scope in India; descriptions of several common trenchless methods; some basic criteria for selecting appropriate trenchless method; and additional considerations for a project using the trenchless technology, such as shaft design and the execution of a successful geotechnical investigation program.

Introduction

Trenchless technology refers to a variety of underground construction methods that require minimal trenching or surface disruption. Trenchless methods do require sinking one or several shafts, but eliminates the need for continuous open trenches. Trenchless methods are attractive solutions in areas where difficult ground conditions exist, high groundwater table, or urban settings with highly congested infrastructure render open trench excavation highly undesirable. Such settings may include pipeline routings under a river, an airport, heavily travelled roadways, or railroad line.

Several methods are available to construct infrastructure assets using trenchless technology. These methods include Horizontal Directional Drilling (HDD), auger boring, pipe ramming, pilot tube method, and micro-tunneling. Trenchless methods are well-suited for small to large diameter (300–3000 mm) infrastructure pipelines and conduits used for sewer, water, gas, electrical, communication, and drainage pipeline systems.

The application of a particular trenchless method is highly dependent on the ground and groundwater conditions along the alignment. As such, a successful trenchless project is dependent to a large degree on developing a reliable geologic/geotechnical profile along the alignment, interpreting the anticipated ground behavior during excavation, and conveying that information to the designer and contractor.

In India, trenchless technologies are of particular interest. Continued population growth in many of India's cities has necessitated the development of strong water and sewerage networks, many of which can be constructed using trenchless methods. These development efforts are being lead by central and state government schemes such as the Jawaharlai Nehru National Urban Renewal Mission (JNNURM) – an effort supported by the World Bank, Asian Development Bank, and Japanese Bank of International Cooperation.

Indian Trenchless Market

India is highly dense in terms of population. As the population continues to grow, it is estimated that almost half of India's 626 districts will require upgrades in utility infrastructures Niranjan (2006). Considering this population growth, the trenchless market in India is theoretically around 50,000 km of infrastructure across a total urban area of 77,370 km^2. Around 63 cities identified in JNNURM are considered to be a priority for development.

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In an effort to reduce the environmental impact of developing and operating sewage treatment networks, underground interceptors constructed using trenchless methods are being viewed as a positive solution in densely populated cities, especially those located along river banks. According to the JNNURM plan, the total value of trenchless projects being developed in the 63 priority cities is around USD 23 billion (Anon, 2010).

Trenchless work has already been initiated in the cities of Delhi, Mumbai, Kolkata, Bangalore, and Hyderabad. Primarily, these projects are for installing water and sewer pipes and are being constructed using pipe jacking or microtunneling methods. HDD has been used for Optical Fibre Cable (OFC) laying for telecom and internet service provider companies.

Pipe rehabilitation projects using trenchless methods as well as pipe ramming and pipe jacking projects are also being carried out in the cities of Delhi, Kolkata, Bangalore, Chennai, Hyderabad, Cochin, Ahmedabad, and other Tier-II cities. Although HDD is a fairly popular trenchless method in India, other methods are not as widespread based upon the number of machines currently in use. For auger boring, there are currently no more than 60 auger machines in use across India. For microtunneling, there are less than 30 microtunnel boring machines (MTBMs) in use.

The primary challenges facing the Indian trenchless market can be summarized as follows:

- Lack of awareness about trenchless methods and their benefits;
- Cost comparisons against cut-and-cover methods that do not take into consideration the evaluation of social costs and benefits;
- A limited pool of specialty contractors skilled in trenchless construction, leading to monopolization of market; and
- Lack of supportive infrastructure.

Common Trenchless Methods

There are five trenchless methods commonly used for new pipeline installation.

a) Horizontal Directional Drilling

Horizontal Directional Drilling (HDD) is a trenchless construction method that can be used for tunnels with diameters as large as 1.4 meters, although diameters less than 1.0 meter are more common. It is a fairly popular trenchless method in India. Over the last 10 years the Indian HDD drill rig population has grown from a non-existent figure to around 400 drill rigs (Niranjan, 2006).

HDD can be used to install infrastructure pipes several hundred to a couple of thousand meters long. With this method, an HDD drill rig advances a drill rod generally about 100 to 150 mm in diameter into the ground, creating a pilot bore. The rod is connected to a slanted face steering bit equipped with a sonde that emits electronic tracking signals for tracking from the surface. The bit is steered along a pre-determined bore path by rotating the bit, pushing the bit, or simultaneously pushing and rotating the bit. As the bit face is advance, bentonite slurry is introduced from inside the drill string to the bit which washes the cuttings back along the outside of the drill string to the pit at the machine insertion side. The pit allows the cuttings to settle out and the slurry is reused in a closed circuit. The HDD process occurs from the surface and other than the slurry pit no shaft is necessary. As this method is commonly used for an undercrossing, the final tunnel profile is generally "U"-shaped. In other words, the rod is inserted at an angle, transitioned to horizontal at the required depth, and then steered upwards to the surface. The radius of curvature for the transition is generally a function of pipe material with a larger radius required for steel pipe than for plastic pipe. The starting angle is generally between 8 and 20 degrees to the horizontal and the exiting angle is generally in the range of 5 to 12 degrees (Bennett et al. 2001) to accommodate the radius of curvature of the pipe when it is pulled back in from the exit side.

At the exit side, a reamer is attached to the pilot rod to enlarge the pilot hole to a diameter that is about 50 percent larger by volume (30 percent by diameter) than the final carrier pipe to be pulled back into the reamed hole. The rig controls the pilot rod such that the reamer is pulled back to the starting point of the tunnel. Again, the cuttings are flushed back to the insertion pit by introducing slurry through the pipe. Depending on the diameter required for the tunnel, one or several reaming passes are made with each pass enlarging the diameter of the tunnel. Depending on the hole size, a final pass is made with a swab to check the hole for stability and to displace material that may have accumulated in the bottom of the reamed hole. Once the required diameter is reached, the final pipeline or conduit is attached to the drill string via a swivel and pulled back through the bored hole.

The final pipeline is generally steel pipe or an engineered plastic, such as PVC or HDPE. Although not as common, ductile iron pipe can be used. Steel and plastic pipe are generally welded into one long string for continuous pullback during installation. The Horizontal Directional Drilling guidelines advocate one continuous pullback during installation to reduce risk associated with stoppages (Conner, 1998). Ductile iron pipe is generally installed by sections. One consideration in the pipe selection is the space available for assembly. If the length of drill hole is long and the lay down area beyond the exit pit is limited, a sectional pipe assembled at the site may be advantageous. Another area of consideration during the engineering phase is the specification of the radius of the bored path. Care must be taken to ensure that the radius of the bored path is within the pipe manufacturer's specifications. If the radius of the path is too small or the breakover curvature at the pullback is too sharp, for example, the pipe may crack, tear, or buckle thus jeopardizing the integrity of the installation (Simicevic et al., 2001). HDD is typically used with pressure pipelines and electrical conduits where a precise line and grade is not needed.

b) Auger Boring

Auger boring is a trenchless method that uses a rotating auger with cutting head attachment for excavation. Immediately trailing the cutting head is a steel casing that simultaneously advances the cutting head and lines the excavated hole. This steel casing is pulled/jacked forward using a motor mounted on a set of rails. Because the steel casing is both bored and jacked, this method is sometimes called the "bore and jack" method. Bore and jack is a method that is used at or above the groundwater level and for installation lengths that are typically less than 100 m.

Generally, a starting and receiving shaft are constructed in conjunction with this trenchless method. The starting pit must be designed in order to accommodate the auger motor/engine, the length of casing, and augers used. As the auger rotates, it carries the spoils back to the starting pit where they can be removed. Therefore, there are many actions happening at the starting pit: assembly of the augers and welding of the steel casing sections, advancing of the steel casing section, turning of the augers by the boring equipment to excavate the ground, and turning the augers to remove the spoils. Auger boring equipment generally does not provide line and grade control during the excavation process. Line and grade is established by setting the rails of the auger boring equipment to the design line and grade. The equipment typically does not have provisions to make line and grade corrections, although auger bore machines with limited steering ability are in use. Therefore, the degree of installation accuracy is generally considered to be about 100 mm to 300 mm or more if the casing or cutter head are deflected during advance.

Although auger boring can be economical when compared with other trenchless methods, it is important to note that the excavated face is not supported. Therefore, auger boring is not a suitable method to use for installations where running soils are expected or below the groundwater table. Additionally, because the auger cannot be steered, the bore and jack method can only be used for straight alignments where there is considerable leeway on line and grade tolerances. One way of overcoming line and grade tolerances is to install an oversize casing and then installing the carrier pipe to design line and grade within the casing. Line and grade tolerances can also be overcome by combining the Pilot Tube Method with auger boring.

The auger boring line and grade would first be established by inserting a pilot tube from an insertion pit to a receiving pit. The pilot tube is a soil displacement method whose installation is continually monitored by a theodolite aimed on a target at the back of the steering head. The pilot tube is approximately 100 mm in diameter consisting of a hollow tube with a lighted target on the steering head. The tube and steering head are advanced in the ground by pushing and turning the steering head as needed to keep the target in sight of the theodolite. By maintaining the theodolite on the target, an accuracy of 10 mm or better can be achieved thus providing a high degree of assurance in maintaining line and grade. Once the pilot tube is installed, the auger boring equipment is connected to the pilot tube. The pilot tube serves as the guide mechanism to maintain the casing on line and grade during the auger boring process. With the pilot tube, the contractor no longer needs to enlarge the casing to compensate for minimal steering control.

c) Pipe Ramming

Pipe ramming is a non-steerable trenchless method that is used to install steel casing for a short distance, such as under a railway or road embankment. Performance is best for drives of up to 50 meters. At shallow depths, installation time can be nearly 40 percent shorter than the time required for auger boring (Coss, 2009). Additionally, pipe ramming can be used for pipe replacement or rehabilitation by simply installing a new pipe over the outside of the old pipe.

The pipe ramming method uses a pneumatic tool to hammer an open-ended steel casing through the ground. Pipe ramming is suitable for a wide range of soil condition, but it is most suited for soft to very soft clays, silts, organic deposits, loose to dense sands above the water table, and soils with cobbles, boulders or other obstacles of significant size but smaller than the casing diameter. The spoils encapsulated inside the casing can be removed during or after the entire length of casing is installed in the ground. Spoils can be removed by auger, compressed air, water jetting, or mechanized equipment for larger casing diameters. A secondary pipe may be inserted through the steel casing depending on the intended use. Pipe ramming is frequently used to install casing under roads and railroads where installation lengths are typically in the range of 30 m to 50 m. Pipe ramming has been used to install casings all the way up to 3600 mm, although the method is more commonly used to install casing or pipes in the range of about 600 mm to 2400 mm. The rammed length is generally a function of soil conditions and the need to satisfy line and grade control. Longer rams have been completed in soft soil conditions using the Pilot Tube Method to set the initial line and grade for the lead casing.

Because the ground above the installation is continuously supported, pipe ramming is a suitable method to use for installations where surface settling may be a concern, such as through loose soils. A variation of pipe ramming is to drive several steel pipes for use as a tunnel roof, with excavation occurring below the roof support.

Generally, pipe ramming is used for installation of casing in the range of 30 to 50 m. Longer installations can be completed if the ground conditions are conducive to driving casing pipe and if proper consideration has been given to the means and methods, and the equipment tooling (e.g., cutting shoe, lubrication, periodic spoil removal).

The applicability of pipe ramming is further enhanced by the flexibility of pit sizes afforded by the length of casing segments selected and reduced surface construction equipment needed to support the topside operations. The previously non-steerable aspect of pipe ramming has been enhanced in recent years with the addition of the Pilot Tube Method.

d) Pipe Jacking & Micro-tunneling

Pipe-jacking is a trenchless construction method that uses powerful hydraulic jacks to push specially designed pipes or casing through the ground. Excavation at the face can be done by hand-mining or with mechanical excavators. A tunnel that is constructed by the pipe-jacking method can have either a straight alignment or a curved alignment. However, the alignment design should be geared towards developing straight alignments and avoiding curved alignments if at all possible. The alignment of the tunnel is controlled at the face and is generally confirmed using specialized monitoring equipment and advanced control systems (e.g., a laser-guidance system).

Micro-tunneling is a form of pipe jacking that includes a cyclical process of simultaneously excavating the ground with a micro-tunneling boring machine (MTBM), removing the spoil, and advancing pipe segments to support the excavation. Generally, a minimum of two shafts are created: a jacking shaft and a receiving shaft. Advancing of pipe segments is achieved using a jacking system set up within the jacking shaft. There may also be one or more intermediate jacking shafts, depending on the length of the tunnel. Although there is no theoretical limit to the length of a micro-tunnel, drives of up to 450 meters are routine. Although there are many considerations that must be made in the course of preparing to construct a micro-tunnel, some that are of particular interest are the selection of a machine for the ground conditions, pipe selection, and lubrication system considerations.

A thrust ring ensures uniform distribution of jacking forces to the pipe. A thrust block provides for transfer of reaction forces to the ground behind the jacking shaft. The size and configuration of a jacking shaft vary with the specific requirements of a project and with the type of equipment used. The size/length of the jacking shaft is generally a function of the pipe length being installed. The receiving pit must be large enough for removal of the MTBM. The pipe may initially be placed on guide rails to establish the correct alignment. The floor of the drive pit is set on the same grade as the pipe alignment. To maintain line and grade, a steerable articulated MTBM is used. The accuracy of alignment can be checked using and following the laser set up in the jacking shaft. An accuracy of plus or minus 0.5 inches can be achieved.

A MTBM uses slurry introduced at the face under pressure to balance the ambient hydrostatic pressure. The slurry mixes with the excavated spoils, which are then transported back to the surface for separation so that the slurry can be reused in the closed circuit. Unlike a conventional tunnel boring machine (TBM), an MTBM does not have an operator stationed inside the machine close to the heading so the machine can be operated under groundwater conditions and in adverse ground conditions. Instead, the path of the machine is steered and controlled by an operator located in a control cabin on the surface. Generally, the final tunnel lining (i.e., carrier pipe) is jacked into place from a jacking shaft where hydraulic jacks simultaneously advance the lining and the machine to a receiving shaft.

The MTBM will generally produce a small amount of overcut. This additional space provides some relief in advancing the pipe. However, lubrication is recommended to ensure a smooth advance. Although bentonite and water lubrication have been used traditionally, there are now many lubrications that are commercially available, including those which contain polymers. In specifying a lubrication system, one must consider the type, viscosity, and amount of lubrication required, and the soil properties into which the lubricant will be introduced.

As with lubrication systems, there are a myriad of options available for selecting a liner pipe. Typical pipe compositions include concrete, steel, clay, and glass-fiber reinforced polymer. Steel sections may be welded together or attached using proprietary systems such as Permalok. The pipe provides continuous excavation support and also sits between the hydraulic jacks and the MTBM. Therefore, the selection of a pipe should take into consideration the thrust forces required. Additional considerations include size, diameter, joint length (especially important along curved alignments), intended use and use as a casing or direct-jacked installation, corrosion, cost, in-service and installation loading, and availability (Losh, 2010).

Part of the internationally accepted definition of micro-tunneling includes an upper size boundary of 1,000 mm. Micro-tunnel equipment with capabilities of satisfying the international and US definition of micro-tunneling is manufactured up to and including 3,000 mm. Defined as a method, micro-tunneling is typically used for designing and constructing tunnels with diameters between 300 and 3,000 mm. Micro-tunneling is used to direct-jack the carrier pipe or a casing into which the carrier pipe is later installed. It is well suited for all ground types–both hard ground and soft ground–and, if warranted in the larger diameters, can be used for tunnels up to 500 m long and beyond. Micro-tunneling is more commonly used for installations between 100 and 300 m depending on equipment size. A favorable advantage of micro-tunneling over other trenchless construction methods is that it simultaneously provides continuous face support, balances ambient hydrostatic conditions, and it replaces the ground with a jacking pipe, thereby maintaining a stable excavation heading.

e) Pilot Tube Method

The Pilot Tube Method is one of the newer trenchless methods, having been introduced in the 1990s. It combines benefits of HDD, auger boring, and traditional pipe jacking. The pilot tube is a soil displacement method whose installation is continually monitored by a theodolite aimed on a target at the back of the steering head. The tubes are guided through the ground by means of a Guided Boring Machine (GBM). Pilot tubes are hollow to provide an optical path for the guidance system and double walled to provide a channel for lubricating fluid transfer to the steering head. Once the pilot tubes reach the receiving pit, the guidance system is no longer required (Iseley and Gokhale, 1997).

The LED/camera system allows for highly accurate drives in line and grade and through various ground conditions. The pilot tube can be installed to an accuracy of 3/8 of an inch or better, thus providing a high degree of assurance in maintaining line and grade. An adapter is attached to the last pilot tube to enlarge the tunnel to the diameter of the pipe. The adapter is equipped with a cutter face attached to an auger set inside a casing pipe or the carrier pipe. The cutter face excavates the ground and the auger transports the cuttings back toward the insertion pit or shaft via the pipe used to advance the cutter face. The adapter is advanced through the ground by continually adding pipe sections and jacking the pipe and cutter head forward with the pilot tube providing guidance. As pipe segments are added, pilot tube sections are removed from the receiving pit or shaft. The pilot tube method can install casing pipe or it can direct jack the carrier pipe into place. Suitable pipe diameters range from 102 to 1,200 mm OD.

The drive length of the pilot tubes are a function of soil conditions and generally range from about 80 to 100 m. Longer drives are feasible in soft ground conditions or if lubrication is used. The pilot tube method is generally used in soft to medium stiff or / loose to medium dense ground conditions. Stiff or dense soil conditions can restrict advance of the pilot tube because the ground cannot be displaced readily. The Pilot Tube Method is not applicable to hard soil, ground with cobbles and boulders, or rock.

Method Selection

Table 1 provides a summary of the trenchless methods discussed in this paper while Table 2 provides a brief selection guide based upon the ground conditions.

Other Considerations

As noted within this paper, the selection of a trenchless method must take into consideration the geotechnical conditions that are expected along the alignment of the tunnel. Therefore, before selecting from several trenchless methods, it is recommended that the subsurface and groundwater profile be fully understood. Understanding the geologic profile and investigating the engineering properties will facilitate an interpretation of how the ground will behave during excavation which provides guidance in machine selection. Core samples

Table 1: Trenchless Methods Summary

Method	Typical Range of Applications			Primary Application
	Depth	Length	Diameter	
Horizontal Directional Drilling (HDD)	< 15 m (50 ft) with walkover system	90-1,800 m (295-6,000 ft)	50-1,200 mm (2-48 in)	Pressure lines, water, gas, cable, conduits
Auger Boring (AB)	Varies	12-150 m (40-500 ft)	200-1,500 mm (8-60 in)	Crossings (All types)
Pipe Ramming (PR)	Varies	12-60 m (40-200 ft)	100-1,830 mm (4-72 in)	Crossings
Pipe Jacking (PJ)	Varies	No theoretical limit - 490 m (1,600 ft)	1,060-3,000 mm (42-120 in)	Sewers, Pressure lines, Crossings
Microtunneling (MT)	Varies	25-225+ m (80-750+ ft)	250-3,000 mm (10-120 in)	Sewer and water installations

Table 2 : Trenchless Method Selection Guide

Soil Type	N Value	HDD	AB	PR	PJ(1)	MT
Cohesive Soils (Clay)	N < 5 (Soft)	O	o	*	o	*
	N = 5 - 15 (Firm)	*	*	*	*	*
	N > 15 (Stiff – Hard)	*	*	*	*	*
Cohesionless Soils (Sand/Silt)	N < 10 (Loose)	O	o	*	*	*
	N = 10 - 30 (Med)	*	*	*	*	*
	N > 30 (Dense)	*	*	*	*	*
	High Ground Water	O	X	o	o	*
Boulders		o	≤ 33%D	≤ 90%D	o	≤ 33%D
Full-face Rock		≤ 15 ksi	≤ 12 ksi	X	≤ 30 ksi	≤ 30 ksi

*: Recommended o: Possible X: Unsuitable (1) Installations above the groundwater level D: Size of largest boulder versus minimum casing diameter
(This table is based on the assumption that work is performed by experienced operators using proper equipment.)

should be taken along the proposed tunnel alignment and the soil materials should be classified according to type or formation. RQD and recovery should be logged to identify areas of highly fractured material or voids which may be present along the alignment. Some of the trenchless methods discussed in this paper are not suitable for alignments where high groundwater inflows may occur.

Another consideration when choosing a trenchless method is the amount of space available at the shafts or insertion pits. Methods such as pipe jacking require the construction of a launch and receiving shaft that are generally about 3 to 10 meters deep, while HDD may only require surface entry and exit pits that are generally 1 to 2 meters deep. Micro-tunneling needs surface space dedicated to the support systems such as the control cabin, slurry separation plant, lubrication tanks, pipe storage area, etc. HDD requires a lay down area for assembly and storage of the pipe prior to the continuous pullback.

Closing Remarks

The growing population of many cities in India has necessitated the development of additional utility infrastructures. In areas where soil, groundwater, or urban settings with highly congested infrastructure render open trench excavation highly undesirable, construction using a trenchless technology is an attractive solution.

Trenchless technology refers to a variety of underground construction methods that require minimal trenching or surface disruption. The elimination of long, continuous open cut trenches make trenchless technology an attractive solution in areas where soil, groundwater, or urban settings with highly congested infrastructure render open cut trench excavation highly undesirable or not practical. Such settings may include pipeline routings under a river, an airport, heavily traveled roadways, railroad line, or a highly congested utility corridor in an urban environment. Trenchless methods are very well suited for small- to large-diameter (300–3000 mm) infrastructure conduits used for sewer, water, drainage pipeline systems, and pedestrian/bicycle tunnels for urban trails.

Examples of trenchless construction methods include horizontal directional drilling, auger boring, pipe ramming, pilot tube method, and micro-tunneling. Each method has advantages associated with it depending upon the intended usage, subsurface characteristics, construction area available and cost and availability of materials. When selecting a trenchless method, these factors should be evaluated so that the most appropriate method for the project is selected.

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