| INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY | **TRENCHLESS TECHNOLOGIES RESOURCE CENTRE** | |
|---|---|---|
| | TRENCHLESS TECHNOLOGY OVERVIEWS | THIRD EDITION |
| | NEW INSTALLATION TECHNIQUES | LAST UPDATED JULY 2009 |

In this ISTT TRENCHLESS TECHNOLOGIES RESOURCE CENTRE Guideline detailed information for the techniques featured below can be accessed by clicking the More> link beside each subsection. Narrow trench and mole ploughing techniques are described in Section 9.

DEFINITION

New Installation includes all processes used to install a pipeline along a new route either as a replacement for an existing line or as a new installation. For information on the criteria required to make the correct method selection for any particular project click here.

This group of processes includes the following technologies

1. OPEN TRENCH METHODS
   a. Conventional open trench methods – not covered in these Guidelines
   b. Narrow trench and mole ploughing – see Section 9 of these Guidelines

2. TRENCHLESS METHODS
   a. Pipe jacking and Microtunnelling. . . More>
   b. Impact Moling and Ramming. . . More>
   c. Auger Boring. . . More>
   d. Horizontal Directional drilling. . . More>
   e. Conventional Tunnelling. . . More>

3. SPOIL HANDLING AND LUBRICATION FLUIDS
   a. Spoil handling techniques and lubrication fluids which are essential to most of the new installation technologies. . . More>

All of the Trenchless Methods discussed in the following involve the use of a machine to excavate a horizontal hole between an entry and an exit point into which the product pipes are pulled or pushed either independently or within a casing pipe which has been installed by the installation technique employed.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

## SELECTING THE CORRECT METHODOLOGY FOR NEW INSTALLATIONS

As with all trenchless technologies knowing the circumstances that have to be dealt with is vitally important to ensure that the correct methodology and technique is utilised for the type of installation required. Some the most important criteria that need to be fully understood are:

- Ground condition
- Installed distance required
- Final requirement of the installed pipeline
- Proximity of other utilities
- Diameter (Hole size)
- Surface access
- Hole or pipe protection
- Potential for Ground movement (heave & subsidence)
- Required working space
- Surrounding environment
- Accuracy (line & grade)
- Timescale limitations (if any)
- Depth of installation
- Type of pipe/casing
- Estimated Cost of all the different options available

This amount of information of course means a significant amount of pre-project investigation and estimating – the detail of much of which is covered elsewhere in these Guidelines.

Essentially, however, knowledge of the prevailing ground conditions across the proposed pipeline route, the type, size, depth and function of the installation required, the pipeline material preferred and the accuracy of installation required, will give a good ‘ball-park’ indication of the trenchless options available for the installation being considered (if any – trenchless technology, it must be understood, is not always an applicable option but should be considered whenever possible due to the environmental, time and social impact advantages it offers).

The individual sub-sections following discuss in more details the circumstances in which they are most suited and when considering a project all should be investigated for applicability to ensure that where two or more options are feasible the most suited is chosen.

Return to Main Overview ▲

| INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY | TRENCHLESS TECHNOLOGY RESOURCE CENTRE | |
|---|---|---|
| | TRENCHLESS TECHNOLOGY GUIDELINES | THIRD EDITION |
| | PIPEJACKING AND MICROTUNNELING | LAST UPDATED JULY 2009 |

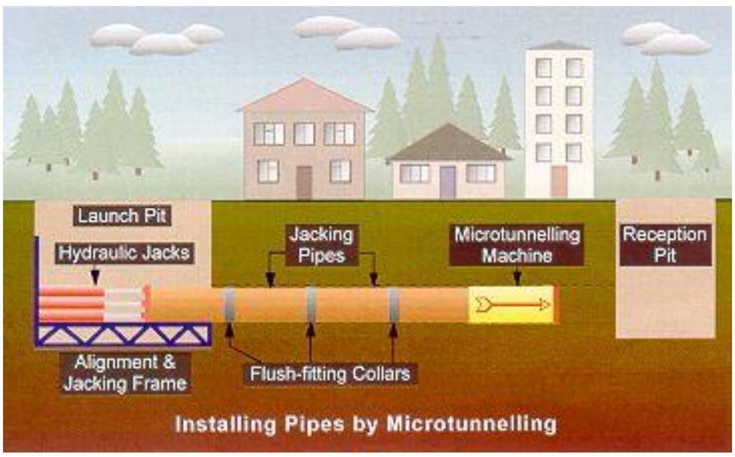
1. OVERVIEW

Pipejacking and microtunnelling, including pilot auger microtunnelling, are essentially from the same family of pipeline installation techniques and can be used for installations from about 120 mm diameter upwards. A pipejack is defined as a system of directly installing pipes behind a shield machine (often manned) by hydraulic jacking from a drive shaft, such that the pipes form a continuous string in the ground. The pipes, which are specially designed to withstand the jacking forces likely to be encountered during installation, normally form the final pipeline once the excavation operation is completed, although they can be used as a casing pipe for the further installation of product pipe(s) if necessary.

Within this description, microtunnelling is specifically defined as being a steerable, remote-controlled shield for installing a pipejack with an internal diameter less than that permissible for man-entry, although in some parts of the world the fact that the system is remotely controlled from surface means it is termed microtunnelling, even at sizes above man-entry minimum diameters. Microtunnellers often use a laser or gyroscopically controlled guidance system to maintain the line and level of the installation, as with larger pipejacking installations. On man-entry sizes, both laser, gyro and normal survey techniques can also be utilised. Pipejacking and microtunnelling techniques are normally used for main line or trunk pipelines.

At the smaller diameter end of the scale, Pilot Auger systems are a type of 'hybrid' between a directional drilling system (see later section) and a 'traditional' microtunnelling system. A drill string is used to bore a pilot hole on a line and level, normally monitored and controlled using a laser theodolite aimed at a target situated just behind the boring head. The bore is reamed using an auger chain to expand the bore after the pilot bore has been completed and the pipe is jacked into position in the bore once this ream is finished. This system is normally for smaller diameter and/or shorter bore lengths such as branch and/or lateral pipeline connections.

More recently, hybrid techniques between microtunnelling and directional drilling have been developed for larger diameter installations. Known as Easy Pipe and Direct Pipe, these techniques will be covered in more detail later.



## 2. APPLICATIONS

Modern technology has, in recent years, enabled these methods to be applied to a wide range of ground conditions from waterlogged sands and gravels, through soft or stiff, dry or waterlogged clays and mudstones, to solid rock.

Pipejacking, microtunnelling and pilot auger systems are well suited to situations where a pipeline has to conform to rigid line and level criteria, since the guidance and control systems allow accurate installation within close limits of the target position. One of the most common applications is for gravity sewers, where not only is the line and level critical but the depth is such that the techniques tend to become more cost-effective when compared with open-cut installation.

Most microtunnelling drives are straight between shafts, although increasingly, in recent years, various companies have developed guidance systems that enable quite complex curved drives to be completed, particularly on longer length, larger diameter bores. Where, because of the curvature of the tunnel, line-of-sight is not possible between the drive shaft and the microtunnelling machine or pipejacking shield, alignment systems based on, for example, gyroscopic devices or moving laser systems may be used as an alternative to the more usual straight-line laser equipment.

The move to more curved drives also enables consultants and contractors to design routes which can reduce if not eliminate the need for intermediate shafts, which were previously almost always required where a pipe route changed direction.

Return To Overview ▲

## 3. EXCAVATION AND SPOIL REMOVAL IN PIPEJACKING

Several different excavation techniques are used in pipejacking operations. The first requirement for a pipejack, microtunnel or a pilot auger drive is that a drive shaft should be sunk. The design of the shaft depends on the installation required, the size of the jacking frame and the lengths of the pipes to be installed. In all cases there is a need to establish a thrust wall against which the jacking frame can operate without causing damage to or misalignment of the shaft itself.

For the excavation of the ground within the pipejack, the first technique is basic hand excavation using an open shield, whereby a miner utilises hand tools, whether powered or not, to remove the ground ahead of the shield. In more difficult ground conditions it is possible to use a backacter, cutter boom or rotating cutter head arrangement. In most cases these systems are used in conjunction with open face shields and rely to a large extent on the ground at the face being self-supporting to some degree. Excavated spoil is removed from the face using mucking skips which are often rail-mounted and winched to and from the face by a continuous rope system. Alternatively, there may be a conveyor-belt loading into a hoisting system at the shaft bottom.

There have been instances where a vacuum system has been employed to remove spoil, whereby broken ground is sucked out of the tunnel. A ‘soft slurry system’ has also been developed, in which a vacuum is used to discharge the slurry.

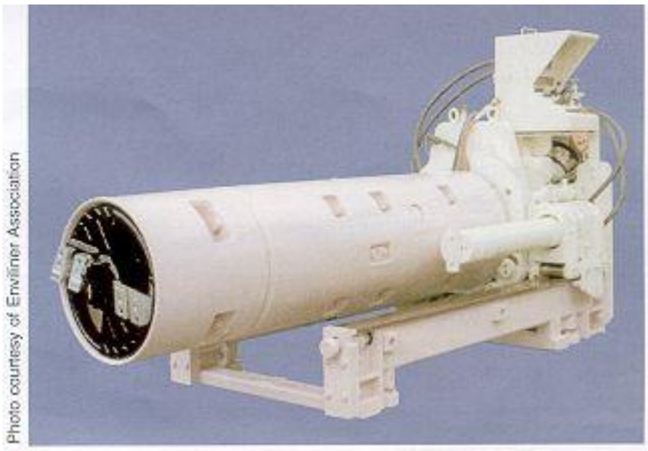
Where the ground is not self-supporting, a closed face shield is generally required. Under such conditions excavation is carried out using a rotating cutter head. The spoil removal technique maintains a sufficient level of support at the face by using either a spoil removal slurry under pressure, or by limiting the amount of broken ground taken from the cutter chamber, maintaining the level of excavated ground within the cutter chamber at a level sufficient to give face support. The latter system is known generally as Earth Pressure Balance.

Recent developments in the field of EPB operations have enabled the technique to be used on projects in a much broader ground condition spectrum. Introducing foaming and other additives to the cutterface has allowed ground condition to modify the spoil output to the EPB system. Whereas normally an EPB system output is fed onto a conveyor or into muck skips, a further development now allows this spoil to be transferred into a slurry system via what is known as a ‘slurry firebox’ for removal

Return To Overview ▲

4. EXCAVATION AND SPOIL REMOVAL IN MICROTUNNELLING

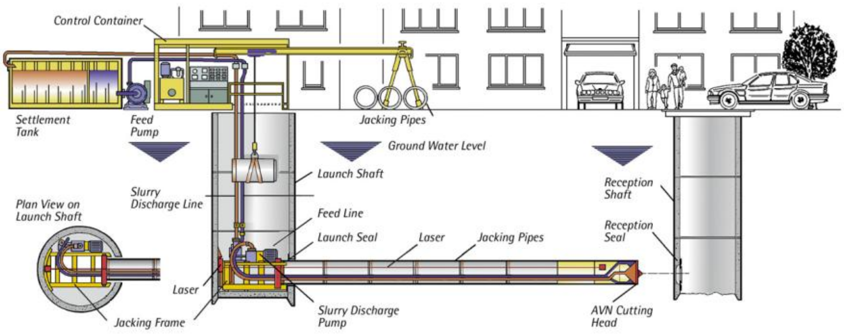
Two predominant systems of spoil removal are employed at the smaller diameters associated with microtunnelling. In reasonably self-supporting soils where the head of ground water pressure does not exceed about 3 to 4 m, it is possible to use an auger flight to remove excavated ground. The auger chain is established inside an auger casing within the jacking pipe. The auger feeds spoil to a muck skip positioned beneath the jacking frame in the start shaft. When full, this is hoisted to the surface, emptied and returned before the drive is continued.




*Auger microtunnelling machine designed for operation in restricted spaces*

In more difficult ground conditions and at higher ground water pressure heads, a recirculating slurry system is often used. The slurry system requires a suspension of bentonite or specially designed man-made polymer (or a combination of the two) to be prepared at the surface. This suspension is pumped to the cutter chamber of the microtunnelling shield via a system of pipes arranged within the jacking pipe. If necessary, the slurry is pressurised to a level required to maintain face support. In the cutter chamber the slurry mixes with the excavated ground, and this mixture normally passes through an in-built cobble crusher, with an eccentric radial motion to ensure that no ground particle larger than the slurry system can handle enters the return side of the system.

The mixture is pumped to the surface, where the soil particles are removed from suspension by simple gravity decantation, or by using centrifugal forces within hydro cyclones or similar apparatus (see section following – Spoil Handling and Lubrication). Chemical flocculants are sometimes added to improve efficiency. The newly cleaned slurry is monitored and reconditioned by the addition of further chemicals, to meet the specification required at the face, and recycled through the system.




*A typical microtunnelling arrangement. Picture courtesy of Herrenknecht AG*

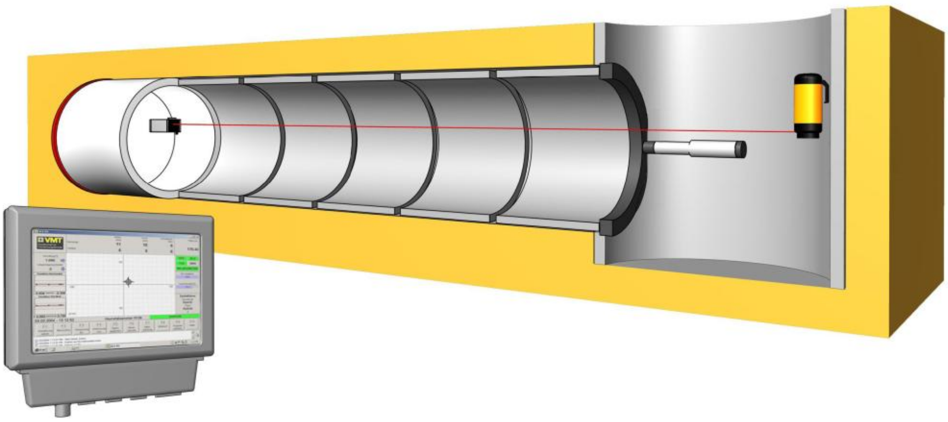
The slurry system has the advantage of being continuous, whereas auger-based methods which require the hoisting of spoil are more cyclical and involve interruptions to the operation of the cutting head.


Photo courtesy of Soltau Microtunnelling

Microtunnelling machines with various cutting head designs

*A microtunneller in its launch positioning the shaft. Picture courtesy of Herrenknecht AG*

There is also a system which utilises a hydraulically controlled sealing door to limit the ground removed during excavation, with spoil removal being completed using a scraper system within the jacking pipe. This system does not normally use a cutter head, but relies on a cutting rim on the leading edge of the shield to loosen the ground, causing it to fall away from the face. The technique has been used successfully, but its application is restricted by limitations on the ground types in which it can operate.




*Laser alignment for guidance control in a microtunnelling operation. Picture courtesy of VMT GmbH*

Two other specialised microtunnelling techniques are available for small bores of less than about 200 mm diameter. The first is a simple compaction method in which the rotating 'cutter' head of the microtunneller does not remove the ground from the face so much as pushes it aside, compacting it around the perimeter of the bore. This system is limited to compactable soil types. The second, generally known as Pilot Auger microtunnelling, employs an initial directional bore phase which can be compared with that used by the majority of directional drilling machines whilst using an excavation method that is similar to that of auger boring or auger microtunnelling.

Where harder ground conditions are encountered there is the possibility to utilise rock cutter heads in place of the softer ground heads more commonly found on microtunnelling machines. These can

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

normally be provided by the machine manufacturer to order. However there is at least one manufacturer that produces specific cutting heads that can be 'retro-fitted' to existing machines either as microtunnel cutter heads or auger boring machine cutter heads. Known by the manufacturer as SBUs they are designed specifically for hard rock environments.

To complete a drive using pipejacking, microtunnelling or pilot auger microtunnelling, a reception shaft is needed. The dimensions of this shaft should be such that the pipejacking or microtunnelling shield, or auger casings in the case of Pilot Auger microtunnelling, can be recovered without difficulty. As these shafts are not normally used for jacking operations there is no need for abnormally high strengths or thrust walls.

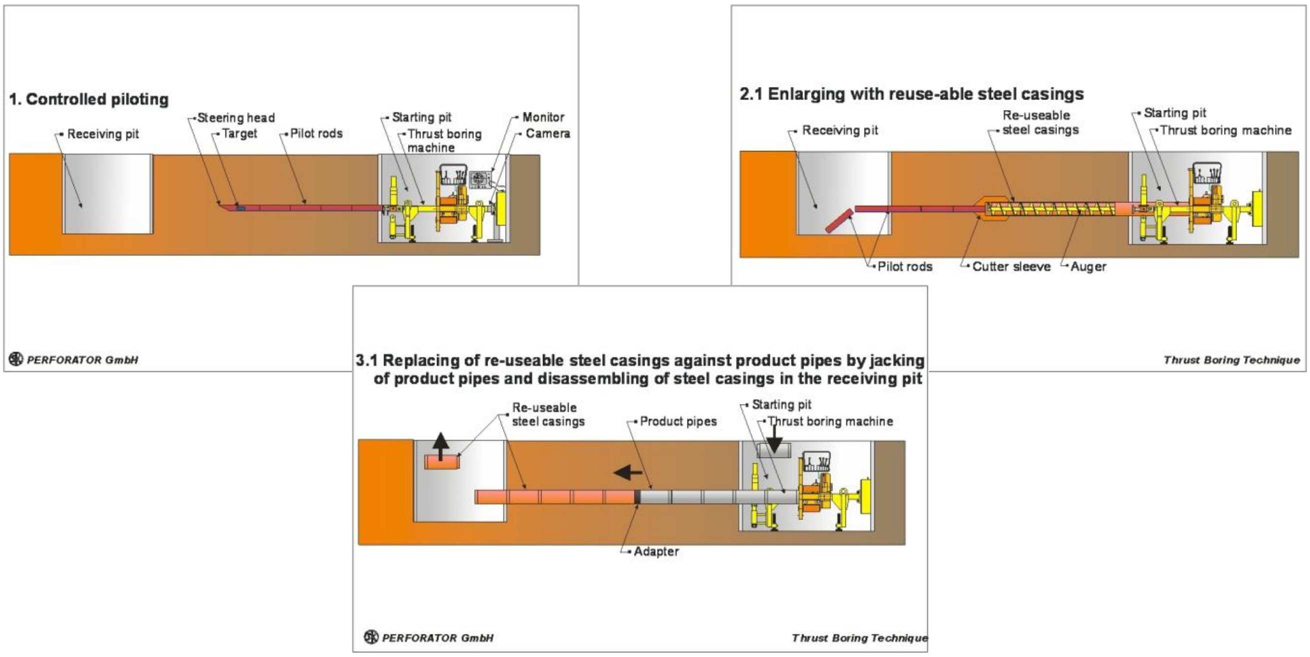
Return To Overview ▲

## 5. EXCAVATION AND SPOIL REMOVAL IN PILOT AUGER MICROTUNNELLING

As previously mentioned the Pilot Auger Microtunnelling system is a type of hybrid between HDD and standard microtunnelling. Initially the jacking frame is established in the shaft bottom with the drill string aligned closely to the required line and level of the finished pipeline. The cutter head on the pilot drill string is an angled rotating head which, when rotated, bores in a straight line. When held at a certain angle the bias of the angled head allows steering to take place. This is where the similarity with HDD come in. The Pilot Bore part of the process is completed using a laser theodolite-based steering system to maintain line and level of the cutter head.

Once the pilot bore is completed normally the system uses an auger-based cutter and spoil removal technique and requires a reaming phase prior to pipe installation to expand the bore diameter to that required to install the product pipe. In highly compactable ground, an expander in front of the lead pipe during the pipejacking phase may be used to achieve this bore expansion. More often however, the system uses a multi-pass installation, with the auger being used to expand the pilot bore diameter. This auger arrangement comprises an auger string inside an auger casing with a cutter head at the lead. The cutter head excavates the ground around the pilot bore expanding the hole as it is jacked through the bore, using the pilot drill string as its directional control. The auger chain is used to remove excavated spoil to the shaft through the auger casing, where it is hoisted to surface, normally in muck skips. Once the auger chain has excavated the full length of the pilot bore the product pipe can be installed.

*Pictures below (courtesy of Perforator) show the three-phase process for Pilot Auger Boring*

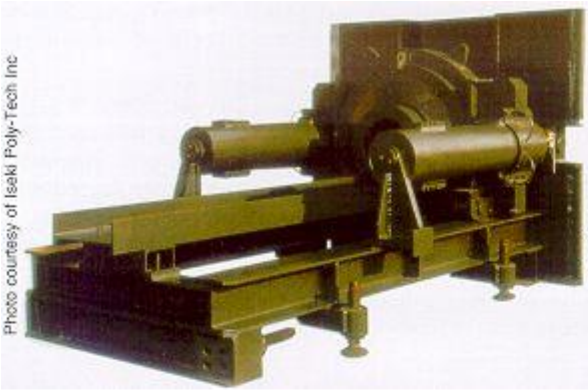


As the pipe is jacked into the bore using the jacking frame, the auger casing is ejected into the reception shaft section by section and recovered for later re-use. Once the auger chain has been totally replaced by the product pipe the installation operation is complete. In cases where the ground is sufficiently self supporting and where the reception end of the drive has very limited access, it may be possible to pull the auger casings back into the launch shaft prior to jacking the product pipe into place, but this is very ground dependent.

Return To Overview ▲

6. JACKING FRAMES

Pipe jacking, microtunnelling and pilot auger systems are more often than not supplied with hydraulically driven jacking frames as part of the purchase package. Frames are designed to provide the level of jacking pressure, via a series of hydraulic jacks, likely to be required by the shield being used on any given project. The requirements for the jacking frame on any project are determined by the ground conditions, length of drive, diameter and the type of shield being used.




*Main jacking station for microtunnelling installation*

Return To Overview ▲

7. INTERJACKS

As well as the main jacking station and particularly on longer and more complex drives where, for example, the length of the pipe string is such that its resistance to movement will exceed the capacity of a practical sized/thrust capacity jacking frame, or where friction forces or ground movement factors will be difficult to overcome, lubrication of a pipe may not be sufficient in itself to allow successful completion of the jacking operation. An option that should be considered before reducing the planned length of a pipejack is the 'Interjack' station.

*An Interjack Station showing the ring of hydraulic rams. Picture courtesy of Herrenknecht AG*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

An interjack station is a ring of hydraulic jacks within a steel framework that is inserted into the pipe string at strategic points. Each interjack divides the pipe string into more manageable jacking lengths. Each length, whether between jacking frame and interjack, interjack and interjack, or interjack and face, can be advanced individually and independently from the rest of the pipe string. It is the equivalent of having several smaller pipejacks in operation at the same time in the one bore, with each interjack using the pipe length behind it as its thrust wall. The use of interjacks reduces the potential for pipe failures, since the maximum force on any individual 'sub-string' depends on the number of pipe sections plus the friction factor over that length of pipe. Each interjack is controlled independently from the operator's station and can, where necessary, be individually lubricated with the correct control and lubrication pump set-up.

Return To Overview ▲

8. GROUND CONDITIONS

The most critical factor in any pipejacking or microtunnelling project is the geology. The subject of site investigation is covered in another Section of these Guidelines, but it is worth repeating here that, unless ground investigation is carried out properly and a thorough knowledge of the conditions likely to be encountered along a pipejack or microtunnel route determined, the risk of putting the wrong type of machine in the ground becomes high. This cannot be over-stressed - on those occasions when pipejacks and microtunnels have failed in the past, this has, most often, been due to unexpected ground conditions rather than to any other reason, including mechanical failure. Such failures sometimes lead to expensive recovery operations, failure of pipes already jacked into the ground or ultimately loss of some very expensive equipment.


*An SBU small diameter cutter head for rock conditions. Picture courtesy of U Mole/Robbins.*

Return To Overview ▲

9. PLANNING

In the early years of development of microtunnelling, and sometimes even still today, some projects were designed around an existing plan to install a pipeline using open cut techniques. Often this was due to the design engineer's lack of knowledge of trenchless technology in general. Contractors were then required to offer an alternative installation using pipejacking technology. Unfortunately, this has always been an inefficient process, as it takes no account of the opportunity for the pipe route to pass beneath existing obstacles.

Most pipejacks and microtunnels can now be planned to remove these restrictions almost completely. By knowing the hydraulic requirements of the pipe, its connection points, the ground types to be encountered and the limitations of access along the required route, shaft positioning, depth and size can be designed in such a way as to minimise the number of excavations required, and thus reduce the number of individual drives on any one pipeline and therefore, generally, the cost.

Such planning not only minimises the physical impact of a construction project by limiting the duration of the work, but also reduces the environmental effects of the project in terms of traffic disruption and amount of ground disturbed. Optimisation of the pipeline length also saves on the quantities of materials required for the project. A further advantage of restricting the amount of excavation is that many clients and highway authorities, particularly in the more developed countries, now insist on the replacement of excavated soils with higher quality backfill when open cutting. This results in the need to transport and dump excavated material, and to quarry and transport the new backfill material. The use of no-dig or minimum excavation techniques reduces the disruption and expense of transportation, quarrying and tipping, whilst also conserving natural materials. In developing countries where new roads etc have only recently been built, the option of open cutting has in some cases been banned by local authorities and governments in favour of the trenchless option.


Curved alignments are possible using modern equipment and techniques

As the techniques of pipejacking and, in particular, microtunnelling are even today, over 30 years after their general introduction, still considered as relatively new to many parts of the world, the potential for standardisation has been limited by the need to establish a depth of experience on which to base published standards relating to conditions in individual countries. In many cases, design engineers looking for a trenchless installation tend to rely on experienced contractors and machine manufacturers to fill in the knowledge gaps that would normally be covered in a standard. To this end, many client organisations are also looking at the use of design and build contracts which bring in experienced potential contractors at an early stage in the planning process to advise on the suitability of systems for the given ground conditions and pipeline requirements. Once a basic plan has been formulated interested contractors take on the project with the remit to complete the final construction design and build the pipeline. This enables previous experience, the latest technologies and the most cost-effective approach to be employed whilst minimising risk to both client and contractor.

Return To Overview ▲

10. PIPES

Given that these techniques require the jacking of a pipe into the ground, often using high jacking forces, the correct choice of pipe with the ability to withstand the required jacking forces during installation and the right properties in terms of final product performance is as important as choosing the right machine to install it in the first place.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

A wide range of pipe materials is available for installation using pipejacking and microtunnelling techniques, the choice depending on the requirements of the client, the ground conditions, transportation costs and the length of pipeline. Materials including reinforced and un-reinforced concrete, polymer concrete (concrete aggregate within a matrix of resin), glass fibre/resin-based pipes, vitrified clayware (both glazed and unglazed), steel, ductile iron and also plastic are available as jacking pipe. In the majority of cases the pipe material is either concrete, polymer-concrete or clayware, manufactured for pipe jacking to strict standards.


Clayware pipes for pipe jacking and micro-tunnelling

Several organisations in the trenchless industry and the majority of clients currently require pipes used in pipejacking and microtunnelling to be manufactured to these recognised standards or the local equivalent, and also that the manufacturer be certified to EN ISO 9002 for quality assurance.

Probably the most important aspects of design in respect of pipes for a pipejack project are the allowable degree of joint deflection and the joint face geometry. In general, the deflection at the pipe joint face should not exceed 0.5°, although deflections of over 1.0° may be permissible for curved drives using appropriate cushioning materials at pipe joints. To ensure squareness, the joint face should be manufactured to the recognised standards, or the local equivalent, and must also be fitted with a suitable packer material to ensure the even distribution of the jacking force across the joint. It is important to be aware that, due to increases in point loading, the maximum permissible jacking load on a given pipe decreases significantly and quickly as the deflection at pipe joints increases. Maintaining, as straight a drive as possible will allow the operator to take full advantage of the design loading of the pipe, should it be required. High deflection will reduce the maximum loading that the pipe string can withstand without fear of pipe failure in the ground.

A significant amount of work has been done on this aspect of microtunnelling and pipejacking over the years and recently research into the behaviour of pipe joint interfaces during the jacking process has been extensive. One development of this research has been the concept of the 'HYDRAULIC JOINT'. The Hydraulic Joint is essentially a fluid filled flexible tube that is used as a 'gasket' between jacking the faces of two jacking pipes which equalises the eccentricity jacking load across the pipe face during the jacking process (*details can be found in the paper – NEW DIMENSIONS IN GUIDANCE AND MONITORING FOR PIPE JACKING AND MICROTUNNELING by Dr. Stefan Trümpi-Althaus and Alexander Seilert from the Moscow International No-Dig 2008 – link*).

An essential feature of pipes for microtunnelling and pipejacking is that the joints do not extend outside the main barrel of the pipe. In other words, the entire joint is contained within the normal pipe wall thickness, unlike conventional pipes for open-trench installation, which usually have spigot and socket joints with sockets of greater external diameter than the rest of the pipe barrel. For microtunnelling and pipejacking, the advantages of a low-friction external pipe surface without protrusions are obvious. In some instance a pipe design with lubrication ports is also useful to allow lubrication fluids to be injected between the pipe wall and the surrounding ground along the length of the drive to minimise friction losses, which in turn reduces the jacking load requirements.

Pipe length varies according to the microtunnelling system used, the pipe diameter and constraints of space. Typical pipe segment lengths usually range from 1.0 to 2.0 metres, although lengths of 0.75 metres are available for small diameters and longer pipes area sometime available on special order. Much of the cost of microtunnelling pipe is in the joints, so the use of longer pipe lengths tends to save cost on pipes; on the other hand, this may require larger shafts.

*Arrival of a microtunnel cutterhead at a reception shaft. Picture courtesy of Herrenknecht AG*

Return To Overview ▲

11. SHAFTS

As mentioned previously, almost all pipejacks and microtunnels are installed between a drive shaft and a reception shaft. The most notable exceptions are those where the exit point of the shield is either directly out of the ground at a set position or under water. Even then, a reception arrangement has to be designed in order to prevent environmental contamination by loss of lubricant or slurry, or to prevent the ingress of water into the pipeline.

Drive shaft requirements vary greatly depending on the machine being used, ground conditions, pipe length and material, length of drive and the type of installation. They may be round, rectangular or oval; sheet piled, segmentally lined, caisson constructed, or even unsupported if ground conditions are good enough and local safety rules permit. Excavation may be by hand, although in the modern world this is more likely to be done using a mechanical excavator or, for perhaps larger diameter shafts, a shaft-sinking rig.

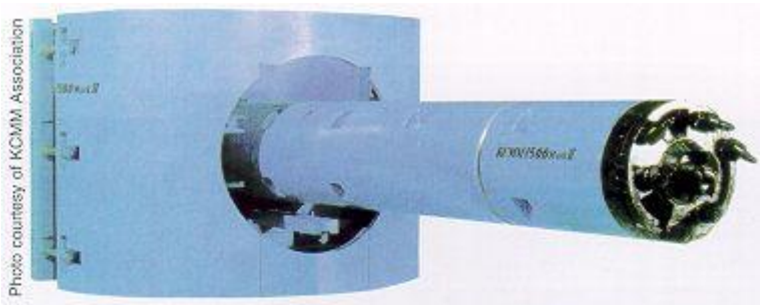
*A schematic of the operation of a shaft sinking rig. Picture courtesy of Herrenknecht AG*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

One factor common to each drive shaft is that there has to be some form of reaction face for the jacking frame to push against. In suitable ground this can simply be the back wall of the shaft, but this is usually not the case and a thrust wall has to be provided. Normally of concrete construction, the thrust wall is an integral part of the shaft support, and may be designed with a soft eye centre to allow the jacking frame to be rotated for a second bore in the opposite direction, or to allow a machine boring from another location to enter the shaft as a reception point. The thrust wall must enable the jacking frame to exert its maximum pushing force whilst maintaining the integrity of the shaft structure and that of the surrounding ground, so as not to compromise the final pipeline structure.

A increasingly popular trend in shaft design has been the removal of the need to create an exit hole with a rubberised seal for the launch of a cutter head. Shafts are increasingly built with a soft eye for the launch of machines as well as reception capability. This enables operators to exit the cutter head from the shaft without having to expose the ground surrounding the shaft and so risk ground water influx or loss of ground around the shaft, causing instability around the new pipe after installation. This in turn increases the safety aspect of the launch of a machine, which often is the most critical part of an operation along with the holing of the machine at the reception end. Requirements for shafts which are needed only for reception duties were mentioned earlier.

Some microtunnelling systems can be designed for use with small drive shafts, and techniques are available, which allow the installation of 1.0 metre long pipes from a shaft of only 2.0 metres diameter.




Auger microtunnelling machine designed to operate from small-diameter shafts

12. HYBRID TECHNOLOGIES USING MICROTUNNELLING SHIELDS

Whilst several options for microtunnelling in terms of capacity to handle different ground conditions, pipeline diameter and route following capability microtunnelling development of the standard technique has become more a case of refinement than innovation. The use of pressure jets in the cutterface to minimise spoil balling and to cut down clay materials and therefore any build up of material at the face is one such refinement.

Recently however one major manufacturer has introduced two new applications which utilise the power and directional control of a microtunneller shield to good effect.

The first is the new process is known as ‘Easy Pipe’. This uses a microtunnelling technique which has been modified with re-useable jacking pipes that owes much of its technique to the horizontal directional drilling field.

Conventional microtunnelling comprises straight-line or curved section bores to install a pipe jacked pipeline between a launch shaft and a target shaft, using a suitable, remote controlled, tunnelling shield for installations of up to 500 m or more and borehole diameters of up to 2,000 mm or more which can be deployed in almost all geological conditions from the softest ground to hard rock (up to 300 MPa UCS) and under almost any groundwater condition.

Conventional microtunnelling usually installs concrete, polymer concrete or clayware pipes, but rarely materials such as steel or PE pipes due to inherent technical problems.

Installing such pipes with microtunnelling is normally overcome by installing conventional jacking pipes only as a carrier or protection pipe into which the actual product pipe is then installed. There are, however, significant cost, time, mobilisation, equipment and practical installation disadvantages with this method.

Conventional horizontal drilling technology on the other hand is a three-phase installation method comprising pilot drilling, bore expansion and product pullback/installation (see later). The technique is normally used for the installation of non-tensile pipelines such as steel, PE or cast iron. Installation rates are generally higher than those for microtunnelling, with maximum lengths of approximately 2,000 m or more but to a maximum pipe diameter of about 1,400 mm. The major disadvantage of HDD is the relatively high sensitivity to geological conditions, in particular, gravel or stony ground with a low cohesion factor, particularly when relatively large boreholes (>800 mm diameter) have to be drilled. The drilling fluid is normally the only support mechanism for keeping the bore open prior to pipe installation. HDD technology also requires a borehole diameter of between 1.3 and 1.5 times that of the product pipe diameter to minimise the risk of jamming due to cave-in and/or sediment in the borehole. This of course brings with it its own technical and economic disadvantages.

The Easy Pipe method has been developed to create a technology that will provide an economic No-Dig solution for the installation of a pre-prepared and tested non-tensile pipeline with relatively large diameters of between 800 and 1,400 mm over comparably long installation lengths of between 500 and 1,000 m in difficult soil types such as gravel, rubble, rock etc.

Typically Step 1 requires a microtunnelling unit to be prepared and assembled in the launch pit. The cutter head is launched and guided in the conventional microtunnelling way, along a given planned alignment. (Construction stage diagrams are shown below).

The difference between the jacking pipes used by Easy Pipe and conventional ones is that the special design allows them to be used as jacking pipes in the forward direction, whilst allowing them to be retracted from the completed bore to pull in the product pipe. This is because the joints between the jacking pipe sections bolt together with a design that will withstand thrust and pullback forces of up to 6,300 kN (630 t). The close proximity of the jacking pipes outer wall to the bore wall also avoids the potential for collapse of the bore in unstable ground formations.

After the cutter head has reached the target pit, it is separated from the jacking pipe string. It is then replaced by a specially designed connection pipe that also connects to the product pipe.

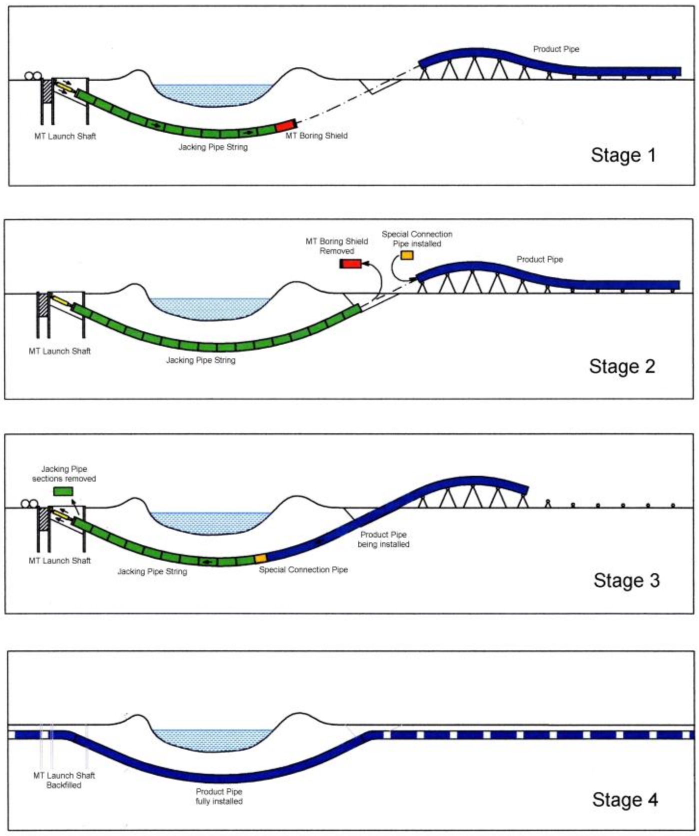
The jacking pipes are then pulled back using the bi-directional jacking frame, simultaneously pulling the product pipe into position. In the launch pit the individual jacking pipes are successively removed, along with all other equipment, until the product pipe arrives at the microtunnel launch shaft. The connection pipe and jacking frame are then removed from the pit, leaving the product pipe in place to be finally connected to the remainder of the pipeline on either side of the obstacle(s) crossed.

The relative merits of Easy Pipe, as compared with conventional microtunnelling and HDD, are most easily shown using a typical project example. The specific advantages and disadvantages of the Easy Pipe method are best examined in terms of Drive Length, Pipe Materials, Quality Standards, Ground Conditions, Drilling Fluid, Borehole Volume, Construction Risk, and Construction Cost. The accompanying table highlights the differing parameters.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

Limited applications of the Easy Pipe technique to date mean that, at present, definitive construction cost data are still being fully evaluated. However, initial estimates suggest that the Easy Pipe method costs are less than for conventional microtunnelling (with carrier pipe) and similar to HDD in ground formations suited for both Easy Pipe and HDD methods (sand, clay etc). In more difficult ground conditions (gravel, rock etc.) cost advantages for Easy Pipe are expected.

Easy Pipe Construction Stages:




The second new technique is DIRECT PIPE. The DIRECT PIPE® method was based on parameters such as the creation of a one-step pipe jacking method, provision of an efficient alternative to existing methods, reduction of site-infrastructure surfaces and minimisation of geological risks (e.g. drill-hole collapse). In addition, disadvantages of the existing methods needed to be eliminated, advantages to be combined and new technologies to be considered. The result is a combination of HDD, Microtunnelling and the Herrenknecht thruster unit 'Pipe Thruster', which has been proven in practice.

The DIRECT PIPE method includes the welding and testing of a pipeline (e.g. steel), which is stored on pulley blocks on the launch side. A microtunnelling machine is mounted in front of the pipeline. To facilitate TBM control, two to three angular steel pipes (connection pipes) are installed between the pipeline and the machine. The Pipe Thruster operates as thrust unit from the launch pit clamping the pipeline on the outside and pushing the machine as well as the pipeline into the ground.

The tunnel face is excavated by a microtunnelling machine similar to the pipe-jacking method, which has been established for several decades. The cutting wheel can be equipped with cutting tools adapted to the specific geological conditions. In contrast to HDD technology, larger boulders, hard rock as well as soft soils (gravel) can be crossed.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

The tunnel face is slurry-supported using a bentonite suspension. The excavated material is removed via a slurry circuit with separation plant in order to separate the spoil from the slurry liquid before feed pumps transport the liquid back to the tunnel face. The microtunnel machine is controlled from the operating container. A gyro compass is used for machine location and guidance.

The micro tunnel machine, pipes and connection pipes are designed conically, which increases the annular gap between the machine or pipe sleeve and the surrounding ground. Bentonite is injected into the annular gap for lubrication from the cutting-wheel assembly. In addition, a lubrication ring is mounted in the transition area between the connection pipe and the product pipeline, where most of the bentonite is added, in order to reduce the friction between the pipeline and the ground to a minimum. In contrast to pipe jacking, a Herrenknecht Pipe Thruster is set up in the launch pit instead of a jacking frame. The Pipe Thruster clamps the pipeline on the outside and pushes the pipes as well as the microtunnelling machine forward incrementally with its thrust cylinders.

The Herrenknecht Pipe Thruster can be adapted to diameters ranging between 500 mm up to 1,200 mm (20 in up to 48 in) by a simple exchange of the clamping unit. The clamping units can be deployed on any pipe type and coating. The two thrust cylinders are designed for a stroke of five meters (5 m) and a maximum pull and push force of 5,000 kN each by advance rates of 5 m/min. The Pipe Thruster is pivotable, the clamping unit can be pushed forward at various angles and the Pipe Thruster, with a total weight of 45 t, has a modular design for easy transportation.

*The launch shaft of a DIRECT PIPE installation showing the Pipe Thruster arrangement.*

In the rear of the Pipe Thruster, a prefabricated and tested product pipeline is positioned on pulley blocks ready to be thrust forward. Different from pipe jacking or microtunnelling, the DIRECT PIPE method allows for an installation of the slurry circuit from the start of the project not requiring a delayed installation and successive extension of the circuit. The slurry and pump system is operated parallel to pipe jacking along the entire drive length.

Due to this site configuration, the product pipeline can be installed in one step. The direct installation of the pipeline allows for continuous drill-hole support preventing bore collapse. The DIRECT PIPE site configuration also allows for a basic launch and target shaft design. It is only necessary to provide a launch seal and firm foundation for the Pipe Thruster on the launch side in order to transmit the thrust forces to the soil. Upon arrival in the target shaft, only the TBM and the connection pipes have to be disassembled as the product pipeline is already in the ground. Feed and slurry lines as well as control, data and power cables are led through the pipeline on special roller assemblies; they can be easily removed from the pipeline using a rope winch to complete the installation. (*See International No-Dig Conference paper: Direct Pipe®: Latest Innovation in Pipeline Construction - Technology and References by M Peters – link*).

Advantages of the DIRECT PIPE method include:

- One-step jacking method, i.e. the product pipeline is pushed into the ground in one step, in contrast to all common methods, which have so far been applied
- Permanent drill-hole support in order to prevent a drill-hole collapse, advantage over HDD
- Cutting wheel and cutting tools of the microtunnelling machine can be adapted to any geological condition, which is particularly beneficial over HDD
- Minimum space required, only on the launch side: Advantage over other methods, which either require considerable storage space on the launch side (pipe jacking/segmental lining), which require considerable space in order to install the product pipeline on the target side (HDD) or which require space on both sides.
- Minimum slurry volume required due to the small overcut
- High performance rates - due to the deployment of the Pipe Thruster and the possibility to install and test entire pipe sections
- The microtunnelling machine, which is equipped with U.N.S. navigation technology and a north-seeking gyro compass, guarantees high-precision target control.

## 13. TRADITIONAL TUNNELLING

More recently, the ISTT has taken the view that, despite previous attitudes, conventional tunnelling could be considered as a trenchless technique if being used for the construction of a pipeline because, in most cases where tunnelling machines or drill and blast systems are used for excavation, it removes the need to excavate large tracts of the surface. This would not apply to 'tunnelling techniques such as Cut & Cover tunnels however. To cover all aspects of conventional tunnelling in these guidelines would require a volume in itself so the topic will not be covered in detail as there is an abundance of information available through main stream tunnelling organisations and on the internet.

Where however, conventional tunnelling is being used to create a pipeline, as opposed to road or rail tunnels etc, what can be said is that up to diameters of around 4 m there is currently a propensity to utilise pipe jacking techniques, as described above, for installation operations, with more conventional techniques being used above these diameters. In these instances, the 'pipe' constructed tends to be in the form of a segmental liner which acts initially as the internal tunnel support mechanism and which, sometimes with a secondary lining, then become the inner wall of the pipeline.

One of the areas of interest that has been covered in International trenchless conferences recently has been the development of these liner segments in particular for the smaller diameter tunnels which form the majority of the installations for pipelines. (*see conference paper: Tunnel Segments for Small Diameters. COMBISEGMENTS® – The Efficient Mould Concept. by M Peters and B Fedunets – link*)

## 14. SUMMARY

a. Pipejacking and microtunnelling can be cost-effective methods of installing new pressure or gravity pipelines through most soil types and at virtually any depth.

b. Precise control of gradient and alignment is possible, and the techniques are particularly suitable for medium to large diameter gravity sewers.
c. The successful installation of a pipeline using pipejacking or microtunnelling techniques relies on a combination of planning, investigation, technology and experienced application. The omission of one of these factors, or the incorrect approach to any of them, can result in the failure of the project or, at least, difficult recovery operations leading to a significant increase in costs.
d. The experience of specialists familiar with the techniques can often make a major contribution, especially if brought in at the earliest possible stage. Field experience has often been shown to be the biggest potential cost saver on any particular project, far outweighing any apparent savings from the use of under-designed equipment, pipe materials or lubrication systems.
e. Innovative combination techniques using both microtunnelling and HDD concepts are expanding the potential market areas for these technologies.
f. Under the right circumstances and for the right installation type, conventional tunnelling can be viewed as a trenchless technique.

Return To Overview ▲

Standards and Codes of Practice:

ASCE 36-01 Standard Construction Guidelines for Microtunneling, CI/ASCE 36-01 American Society of Civil Engineers / 01-Dec-2001 / 56 pages ISBN: 0784405727

Guide to Best Practice for the Installation of Pipe Jacks and Microtunnels 1995 Pipe Jacking Association (PJA)

EN 295-7 Vitrified clay pipes and fitting and pipe joints for drains and sewers - Part 7: Requirements for vitrified clay pipes and joints for pipe jacking

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

<table>
<tr><td rowspan="3">INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY</td><td colspan="2">TRENCHLESS TECHNOLOGIES RESOURCE CENTRE</td></tr>
<tr><td>TRENCHLESS TECHNOLOGY GUIDELINES</td><td>THIRD EDITION</td></tr>
<tr><td>IMPACT MOLING AND RAMMING</td><td>LAST UPDATED JULY 2009</td></tr>
</table>

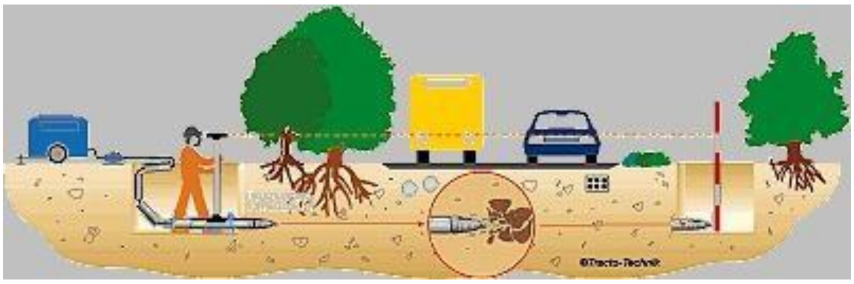
## 1. OVERVIEW

Although the first attempts at producing Impact Mole systems occurred during World War I, practical Impact Moles first appeared from Poland and Russia in the 1960s. The early systems were heavy for the size of bore, and frequently gave problems such as large deviation from the intended route, or the unit even being lost in the ground. Since then, impact moles have been developed to a much finer degree, and are now probably one of the most commonly used of all items of trenchless equipment worldwide, to the point where many operators now are not even aware of their 'trenchless' origins. They offer solutions to a wide range of installation problems, particularly over short distances. The simplicity of the tool and the minimal amount of training required, to ensure operators know how to work with them safely and correctly, is what has made the impact mole the common tool it has become today.

Impact moling and Ramming essentially use the same type of equipment to install new utility services underground, but they employ two different application techniques. Each will be discussed individually in this Section.

## 2. IMPACT MOLING

Impact moling, or 'Earth Piercing' as it is commonly known in North America, is defined as the creation of a bore by the use of a tool that comprises a percussive hammer within a suitable cylindrical casing, generally torpedo shaped. The hammer may be powered hydraulically or pneumatically. The term is usually associated with non-steered or limited steering devices without rigid attachment to the launch pit, relying for forward movement upon the internal hammer action to overcome the frictional resistance of the ground. During operation, the soil is displaced, not removed. An unsupported bore may be formed in suitable ground, or a pipe may be drawn or pushed in immediately behind the impact moling tool. Cables may also be pulled in.



Schematic of the Impact Moling process.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

A distinction needs to be drawn between percussive moles discussed in this Section, and hydraulic moles that operate by expansion rather than hammer action. Expanding hydraulic moles are generally used for pipe-bursting applications (see On-Line Replacement Section) rather than new installations. Although hydraulically driven percussive moles are available, most are powered by compressed air. A potential drawback of air-driven moles, particularly for water supply installations, is contamination of the product pipe by lubricating oil in the exhaust, although there are methods of overcoming this. Hydraulic moles require two hoses (flow and return), and tend to have greater mechanical complexity.

The basic mechanism of Impact Moling is the reciprocating action of the pneumatically, or hydraulically, powered hammer within the cylindrical steel body. The piston is driven forward and, on striking the forward end of the unit, imparts its kinetic energy to the body, which is driven forward. The energy of the piston for the return stroke is regulated so as to reposition it for the next forward stroke, rather than reversing the unit out of the bore (unless required to do so).

*Impact Moling hammer in it's launch pit. Picture courtesy of Tracto-Technik.*

Repeated impacts of the hammer piston advance the whole unit through the ground. As forward movement takes place, the soil in front of the mole is forced aside and compacted by the conical or stepped nose to form the walls of the bore. The power of the unit is also often used to pull the product pipe, cable or cable duct through the bore at the same time as the impact mole advances.

Impact moling tools are known by several other names including earth piercing tools, soil displacement hammers, impact hammers, percussive moles or pneumatic moles, depending on the term used by the manufacturer and the region of the world where the equipment is being used.

## 2.1 Ground Conditions

The compacting action of the impact mole means that, in general, it can operate only in soils that can be compressed or displaced. Obstacles along the bore path can deflect or stop the mole, so a thorough ground investigation regime is essential prior to work commencing, in order to establish a clear route. This should include not only knowledge of existing utilities but also soil sampling to ensure that

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

cobbles or boulders are unlikely impede progress. Some impact mole designs have been developed to try to overcome unexpected obstacles or even relatively small known ones.

2.2 Alignment and Launch

Motive power is supplied to the rear of the impact mole via pneumatic or hydraulic pressure pipes, which normally pass through the product pipe or duct, or run alongside the new cable.

Once the ground investigation has been completed and the desired route established, the following procedure should be followed to complete an impact mole bore.

A launch pit and a reception pit are first excavated at the ends of the bore path, to a little over the planned depth of the installation. The launch cradle, if used, is then set up, or the mole can be positioned directly on the floor of the launch pit. Using a ranging rod in the reception pit and a sighting telescope in the launch pit, the initial line of the bore is established by physically aiming the mole towards the ranging rod target. The mole is launched and allowed to advance a short distance. The line is checked for a final time before the whole of the body of the mole enters the ground. If the line is not correct, the bore is restarted. The bore is completed when the mole arrives at the reception pit, and the tool can be removed after the product pipe, duct or cable has been drawn into the pit.


*Using a ranging rod to aling an impact mole prior to launch. Picture courtesy of HammerHead*

2.3 Monitoring

Most moles can now be fitted with radio sondes, similar to those used for monitoring the progress of directional drilling units (see Horizontal Directional Drilling Section below), which allow the progress of the mole to be followed closely both in direction relative to the planned course, and in depth. Sondes can be fitted either to the rear of the impact mole or, increasingly within the front end.

Although rear-mounted sondes give an indication of progress, they provide less useful information than front-mounted units. Depending on the mole size and length, the sonde can be some distance from the penetrating end of the tool, and therefore responds much later than a front-mounted sonde to changes in the bore path. Front- or nose-mounted sondes react immediately to changes in direction and pitch, and so give the operator more time to halt the bore and assess the next move. However, nose-mounted sondes have to be far more robust and well protected, as they must withstand the shock of the drive forces applied to the front of the unit by the hammer action.

Whilst most impact moles are non-steerable, there are a few steerable tools that normally use steering vanes outside the body, or an angled head (that is directionally adjusted through keyhole excavations) to apply corrective action. The latter system does however require regular monitoring and adjusting because as the tool progresses, without regular adjustment, the directional shift will increase. Monitoring is achieved using similar systems to those already described. These systems have experienced limited use in the field.

If a bore is forced off-line or prevented from advancing by an obstacle, it is often easier to dig down to the unit, remove the obstruction, realign the mole and re-launch it, rather than to start the bore again. This is often aided by the reversing facility that all modern impact moles now have, which enables the unit to be backed away from an obstruction to a point where it was on the correct line and level. After removing the obstacle and backfilling the hole, the mole is restarted on the intended course.

## 2.4 Applications

Because impact moling is generally unsteered, the technique is most suitable for shorter bores: a straighter bore can often be maintained more easily at larger diameters and with longer mole bodies. Diameters range from about 45 to 200 mm depending on the pipe or cable being installed.

Because of soil compaction restrictions and the need to minimise or eliminate surface heave, a widely accepted rule for impact moling installations is that there should be at least 1 m of depth for every 100 mm diameter of the tool. As most utility mains and services (except sewers) are laid at depths of less than 2 m in most countries, this gives an effective upper limit of 200 mm for impact mole diameters.

Despite this limitation, impact moling can be a very cost-effective method of installing small to medium sized pipes, ducts and cables for a broad range of utilities including gas, electricity, water and telecommunications. The technique is in common use for simple road crossings and the installation of service connections between main lines and individual properties as well as for environmental protection on installations running beneath mature trees, street furniture and protected structures. Moles are relatively easy to use, monitor and maintain in the field, and many utility companies carry moling systems as standard equipment for every team on installation and service vehicles.

In more recent years there have been two new interesting areas for the application of impact moles. These are HDD Assist/Rescue (see Horizontal Directional Drilling Section) and Piling both of which are described in detail under Ramming Hammers.

## 2.5 Head Types

Two basic head shapes are commonly used for impact moles. The first is the simple cone which, during operation, pierces the ground and pushes the soil aside. The second is the step or chisel head, which is effectively a stepped cone. In normal operation the spaces between the steps fill with soil, and the head operates as a simple cone. However, when the head strikes an obstacle, the stepped edges concentrate the impact energy against the obstruction. Whereas a smooth cone would tend to

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

be deflected by an obstacle, the stepped shape may apply sufficient longitudinal force to move the obstruction or shatter it, reducing the risk of going off line.

Many moles have fixed heads, which means the head is an integral part of the mole body once the unit is assembled. When the piston operates, it acts on the whole of the mole body propelling it forward.

An alternative is the moving head mole, in which the head is not directly attached to the body, but floats on a shaft passing through the front end of the mole. The rear of this shaft is the anvil against which the reciprocating hammer strikes. Using this configuration, the initial and highest impact force from the hammer is transferred to the head alone, advancing it into the ground. Several advantages for this system are claimed, including higher impact energy to penetrate harder ground and move or break up obstacles. The body of the mole acts as an initial directional anchor to the head as it drives forward, giving better directional control.

## 2.6 Installation Variations

In addition to the basic installation technique, there are some variations in how impact moles can be operated, and how installations are performed for different types of utility. Where the inner surface of a new pipeline has to be kept clean, for example a new drinking water pipe, two methods have been developed for use with pneumatic moles.

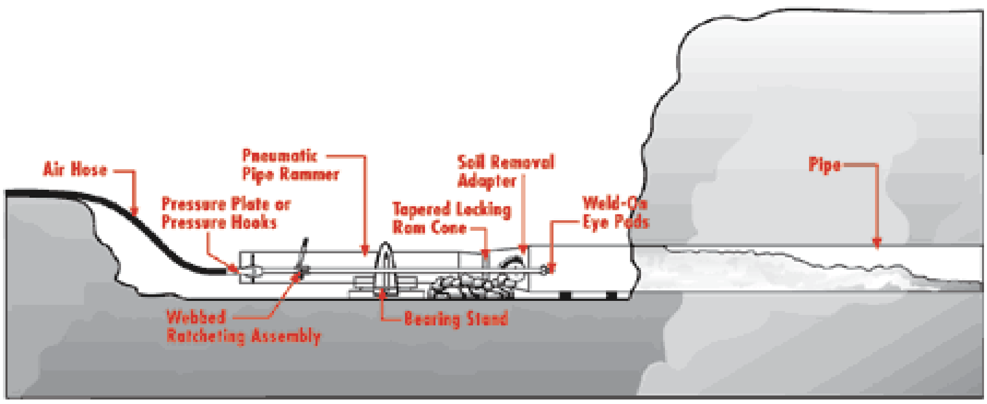
Pneumatic moles operate with compressed air, which carries the lubricating oil required by the moving parts in the unit. Since compressed air is not recycled as in hydraulic systems, used air is vented out of the mole. In most cases, this is done through the rear of the mole into the pipeline being drawn in behind, which tends to coat the inner wall of the pipe with an oil film that can be difficult to remove. The oil film can be ignored if it is unlikely to cause a problem, but for drinking water the oil is usually regarded as unacceptable.

To overcome the problem, installation is often done using a liner film within the pipeline. Exhaust air deposits the oil film on the liner, which is removed on completion of the bore, leaving a clean inner surface. To avoid the need for a liner, moles have become available which vent used compressed air from the front of the machine. This air then discharges along the outside of the new pipe, without affecting the inner surface.

Return To Overview ▲

## 3. PIPE RAMMING

Pipe Ramming is a non-steerable system of forming a bore by driving a steel casing, usually open-ended, using a percussive hammer from a drive pit. The soil may be removed from an open-ended casing by augering, jetting (with water) or compressed air. In appropriate ground conditions a closed casing may be used.




*Schematic of the Pipe Ramming Technique.*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

3.1 Applications

Pipe Ramming is most often used to install new pipelines or casings into which new utilities will be installed. Installation distances have increased dramatically in recent years from about 50 meters, on average, to up to 100 meters today. Steel pipe is used for the casing, as no other material is strong enough to withstand the impact forces generated by the hammer. The technique is often favored for crossings beneath railways, roads and waterways. Once the steel pipe is installed, it can be used as a pipeline in its own right, or as ducting for most types of pipe or cable.

Bores up to 3,000 mm diameter have been installed in suitable ground conditions, using impact ramming hammers of up to 800 mm diameter generating ramming forces of up to 40,500 Nm. But, as with all trenchless systems, much of the capability of this equipment depends very much on the prevailing ground conditions and the skills and experience of the operator.

Piling utilises an impact mole or more commonly a Ramming Hammer in the vertical plane to push steel pipe into the ground to a required depth. The pipe is then either used directly as the pile or the ground within the pipe is removed and replaced with concrete to create the required structure. This option, in recent years, has found an increasing market in the piling industry where they have been used vertically to install support piles on smaller projects where larger piling units would be very costly, short vertical installations which need to be installed with minimal digging, vertical accesses which go to a short depth or on sites where larger/heavier equipment access is restricted or undesirable.

HDD Assist/Rescue is probably one of the most useful developments for Ramming Hammers over the past few years. With HDD installations there is always the possibility that ground conditions will vary to an extent that has not been predicted by ground investigation surveys, whether this be due to unknown ground or variations in ground water due to changing weather patterns. Should a drill string or pipe being pulled into a bore get stuck in such circumstances, Ramming Hammers are now ready to help. Techniques have been developed whereby a Ramming Hammer can be attached to a drill string or pipeline in a manner that can enable operators to recover the stuck equipment or to assist in completing the product pipe placement. 'Recovery' or rescue is achieved by utilising the Ramming Hammer in conjunction with the power of the HDD rig in a direction opposite to that in which it got stuck, so pulling the equipment back out of the ground to start again if required. 'Assistance' is achieved by connecting the Ramming Hammer to the free end of the pipe string with the hammer working in the direction of the pipe pull. The extra impetus on the pipe string, supplied by the hammer working in conjunction with the pulling power of the HHD rig, more often than not is sufficient to allow the pipe pull-in to be completed.

*A Ramming Hammer used in an HDD recovery operation. Picture courtesy of Tracto-Technik.*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

3.2 Set-up

A typical ramming operation requires the establishment of a solid base, normally a concrete mat, on the launch side of the installation. This mat will usually be either against the side of a slope or in a start pit. Guide rails set to the line of the bore are then installed on the mat. The first length of steel pipe is positioned on the guide rails, a cutting edge is formed or fitted to the lead end of the pipe, and the ramming hammer is attached to the rear of the pipe. Depending on the diameter, inserts may have to be used to ensure solid and uniform contact between the hammer and the pipe.

The power supply is attached and the hammer started. The ramming hammer forces the steel pipe into the ground along the line dictated by the guide rails. When one pipe has been driven, the hammer is stopped and removed, and the next length of steel pipe is welded in place. The cycle is repeated until the leading edge of the first pipe arrives at the reception end or shaft.

*A Ramming Hammer in position to ram a steel casing. Picture courtesy of Earth Tool Corporation.*

As with impact moling, thorough ground investigation is an essential requirement of pipe ramming projects. Large obstacles can deflect a pipe off course, or may damage the cutting edge, causing a steering bias. As there is usually no means of monitoring the direction of the pipe during a bore, it is vital to establish a clear bore path prior to work commencing.

3.3 Bore Options

Depending on the nature of the ground, ramming may be carried out with either open ended or closed-end pipe. Open-ended ramming is generally preferable, having several advantages including lower reaction against the ramming force, since only the cutting edge is pushed against the ground. Harder ground can be penetrated by open-ended ramming, as the soil does not have to be compressible. Because the surface area of pipe presented to an obstacle is far less with an open-ended pipe, there is also less likelihood of the pipe deflecting.

However, for open-ended ramming the ground has to be relatively self-supporting, otherwise there may be loss of ground ahead of the cutting edge, as soil moves into the open pipe and flows along it to the start pit. In severe cases, this could cause surface subsidence or loss of support to adjacent pipelines or other services. Closed-end ramming may be effective under such conditions, as soil is displaced around the pipe and compacted around the wall of the bore. As with impact moling, there is the risk of surface heave during a compacting bore.

When using an open-ended system, the cylinder of ground within the circumference of the cutting edge stays inside the pipe during the bore. Over the short distances normally undertaken with pipe ramming, this accumulation of spoil is not usually a problem.

However, for longer bores, it should be remembered that the spoil adds to the weight of the pipe string being rammed, and will therefore affect advance rates. In some instances it may be advisable to clean out spoil from the pipe during pipe string extension works, to limit the extra burden on the ramming hammer. Depending on diameter, this can be done either manually or by means of a scraper winch system.

If intermediate cleaning is not required and the spoil remains in the pipe for the whole bore, there are techniques other than shovels or scrapers for achieving spoil removal. On arrival at the reception pit, the open end of the pipe can be sealed with a suitable plug. Pressurised water or compressed air is then introduced between spoil and seal, and the cylinder of soil in the pipe is forced out into the launch pit where it can be removed. The seal is then removed, and the pipe or casing cleaned and put into service.

The principles of both impact moling and pipe ramming are relatively simple, and these techniques can offer highly cost-effective solutions to relatively short length installation projects.

Return To Overview ▲

## 4. PIPE BURSTING

Impact hammers are also used for various forms of on-line pipeline replacement work. This application is covered elsewhere in the On-Line Replacement section.

## 5. SUMMARY

1. Moling is one of the simplest and most widely used no-dig techniques, especially for small diameter service installation over relatively short distances.
2. With some exceptions, moles are not steerable and rely on launch orientation and soil conditions to follow the desired route.
3. Pipe ramming is a common method of installing steel casings in a straight line, and is frequently used under railway and road embankments.
4. As with moling, pipe ramming is generally employed for relatively short drives, and is not a steerable technique.
5. Pipe rammers can install large diameter casings. Although the steel casing can act as the product pipe, it is more usual for it to be treated as a duct through which conventional mains or services are installed.

Return To Overview ▲

| | | |
|---|---|---|
| INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY | **TRENCHLESS TECHNOLOGIES RESOURCE CENTRE** | |
| | TRENCHLESS TECHNOLOGY GUIDELINES | THIRD EDITION |
| | AUGER BORING | LAST UPDATED JULY 2009 |

1. OVERVIEW

Auger Boring is a technique for the bored installation of a casing pipe into the ground. Product pipe or final services are then usually installed within the casing pipe as required. It could be described as a pipe jacking technique but as the casing pipe is an integral part of the construction methodology it has been decided to give it its own section within the ISTT Guidelines. The technique is normally found to be cheaper than full microtunnelling or pipe jacking but does have limitations on the range of ground in which it can operate effectively in its standard form, in particular very wet ground. With special adaptation the system can operate in harder ground including rock. Depth limits are dependent on the size of excavation required to access the auger boring unit and the practical length of pipe that can be installed from what is generally quite a large dimension launch shaft/pit.

A typical Auger Boring set up**.** *Picture courtesy of Allen Watson Ltd*

2. APPLICATIONS

As the name Auger Boring implies, the excavation technique employed is that of using a rotating auger chain/flight fitted with a cutter head. The cutter head is driven by, and is positioned at the lead end of, an auger string that has been established within the casing pipe, the auger diameter being dimensioned to the just below the full diameter of the casing to allow rotation. Rotating the helical auger chain within the casing pipe allows the cutter head to excavate the ground at the face, with spoil being removed back along the auger string within the casing pipe to the launch shaft or pit. Spoil is removed by hand or mechanically or placed into muck skips for removal as it exits the casing pipe.

The system is normally an unguided technique and is not generally used for installations requiring very high accuracy in line and level, although experienced operators can achieve very good accuracy where ground conditions permit. Some systems have been developed that allow for some limited steering capability to be applied to the cutter head or to the casing pipe to counter minor deviations as they occur.

The system is normally applied to the softer ground conditions like clay soils and soils with contained cobbles. Some systems have been designed to handle softer rock formations with the use of a special cutter head. More recently one manufacturer has developed a system known as the SBU (for Small Boring Unit) which are specially designed cutterhead units that are welded to the end of the auger boring casing. The SBU-A is a small diameter cutterhead and thrust bearing assembly for 600 mm to 1.8 m diameter that can be used with any auger boring machine  from 900 mm to 1.8 m diameter. The SBU-A is welded to the lead casing. The contractor-supplied auger pilots directly onto a taper hex shaft in the thrust bearing assembly. There is also an SBU-M which is a motorized, manned-entry rock boring attachment meant to bore in a variety of rock types with Unconfined Compressive Strengths (UCS) of 25 to over 175 MPa. It is made for use with any Auger Boring Machine from 1.2 to 2.08 m or any standard pipe jacking unit. The SBU-M is made for longer bores, and maintains line and grade for the length of the bore. The SBU-M is similar to the Robbins Small Boring Unit (SBU-A). There is also a Rockhead version for diameters of 1.35 m and 2.00 m.


An SBU unit for use with auger boring systems.
*Picture courtesy of Robbins and U Mole.*

High water table and flowing ground does cause a problem to auger boring. The auger flight is not generally a sealed system and the auger chain is the only means of preventing loss of ground from the face. It is neither water tight or sealable.


**Typical Auger Boring machines.**
*Pictures courtesy of Barbco (left) and American Augers (right)*

Return To Overview ▲

## 3. EXCAVATION AND SPOIL REMOVAL USING AUGER BORING

Generally, Auger Boring systems are diesel or hydraulically driven and are used for non-displacement boring operations. They are designed for the installation of casing pipes from about 102 to 1,830 mm diameter over distances of up to around 200 metres although larger diameter is normally associated with longer bores.

The installation process requires the establishment of a launch pit, dimensioned to allow the installation and operation of the auger boring machine, and the required pipe length to be accommodated within it. As the casing pipe is generally manufactured from steel, the welding together of lengths to create the total pipe length required is not a problem.

The auger boring machine, usually operated by a single operator using controls on the body of the machine, is set up on a set of tracks or rack and pinion system on the line and level required for the casing installation. The first casing pipe length is positioned at the head of the machine with its auger flight already installed. The cutter head is at the head of this auger flight. The auger boring machine rotates the auger flight, and thus the cutter head, as it thrusts forwards along the track or rack and pinion arrangement. The cutter head excavates the ground and removes spoil to the start pit for manual or mechanical removal. When the auger boring machine reaches the end of its stroke, governed by the length of the track/rack arrangement, the casing pipe is released and the machine is withdrawn to its original starting point. A new length of pipe is positioned with its own auger flight in place, the auger flights are connected together to drive the cutter head and the pipe ends welded to form a continuous pipe length. The excavation and thrust process is repeated in this way until the drive length required is completed, with the arrival of the cutter head at a reception pit.

The drive is completed with the withdrawal of the auger flight chain from within the casing pipe. The casing is cleaned to remove all remaining spoil and the product pipe, or cable, installed.

## 4. SUMMARY

1. Auger Boring tends to be for straight, unsteered drives in softer ground over relatively short bores, although some systems offer limited steering capability and some of te separate boring head now available do offer greater steering capacity.
2. Ground conditions may mean limitations in terms of depth and capability, particularly in high water table areas.
3. Rock condition installations may be possible with specialised equipment.
4. Auger Boring does not generally install product pipes directly, but installs casing pipes, into which product pipes or services may be placed later.
5. Launch pit dimensions for Auger boring machines may mean access requirement limitations.
6. Lower cost option than ‘traditional’ microtunnelling, provided ground conditions and site situation are favourable.

Return To Overview ▲

| iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY | **TRENCHLESS TECHNOLOGIES RESOURCE CENTRE** | |
|---|---|---|
| | TRENCHLESS TECHNOLOGY GUIDELINES | THIRD EDITION |
| | HORIZONTAL DIRECTIONAL DRILLING | LAST UPDATED JULY 2009 |

1. OVERVIEW

Horizontal directional drilling or HDD techniques (in some countries also known as Guided Boring) are used for the trenchless installation of new pipelines, ducts and cables. The drill path may be straight or gradually curved, and the direction of the drilling head can be adjusted at any stage during the initial pilot bore to steer around obstacles or under highways, rivers or railways and to follow a pre-planned course. Using the correct type of drilling rig, bores can be carried out between pre-excavated launch and reception pits or from the surface by setting the machine to initially drill into the ground at a shallow angle.


A Horizontal Directional Drilling rig. *Picture courtesy of Ditch Witch*

In terms of scale and capability, HDD tends to fall between the techniques of impact moling and microtunnelling. The term HDD is frequently used to describe the heavier end of the market such as major river, canal and highway crossings often covering long distances, but there is now such an overlap in equipment capabilities that it is probably unnecessary and unhelpful to draw a line between HDD and Guided Boring. Pullback capacity, or the power available in tons, is commonly used to classify HHD systems. The higher the pullback capacity generally the larger the machine and the larger diameter pipe, duct or cable it can install. Higher pullback capacity may also be an indication of the maximum length that the rig can operate over, i.e. the higher the pullback capacity the longer the bore can be. This is very dependent however on the prevailing ground conditions and the diameter of the pipe, duct or cable being installed.

Installation of the product pipe or duct is usually a two-stage operation. A pilot hole is first drilled along the required path using position-monitoring equipment to provide the steering information (see later), and the bore is then back-reamed, in a single or multistage operation depending on the ground conditions and project requirements, to a larger diameter that is designed to accommodate the product pipe. During the final 'pullback' stage, the product pipe is attached to the reamer by means of a swivel connector, and is pulled into the enlarged bore as the drill string is withdrawn.

In earlier years, HDD was used mainly for the installation of pressure pipes and cable ducts, where precise gradients are not usually critical, rather than for gravity pipelines which demand close tolerances in vertical alignment in order to meet hydraulic design criteria. However, more recently, drilling machines and guidance systems have offered improved control and positioning monitoring accuracy in suitable ground conditions, and the technique has become increasingly popular for gravity pipelines because of this.

Equipment capabilities have improved in recent years, both in the power and diameter of installation available and in the wider range of ground conditions that can be bored, and the advantages of trenchless technology for new construction have become more widely appreciated. Some utility companies now have a presumption against open-cut techniques (particularly in roads) where a no-dig alternative is available. Apart from the obvious environmental benefits of trenchless installation, the relative cost of HDD has fallen to below that of trenching for many applications, even ignoring the social costs of traffic disruption and delay.

Return To Overview ▲

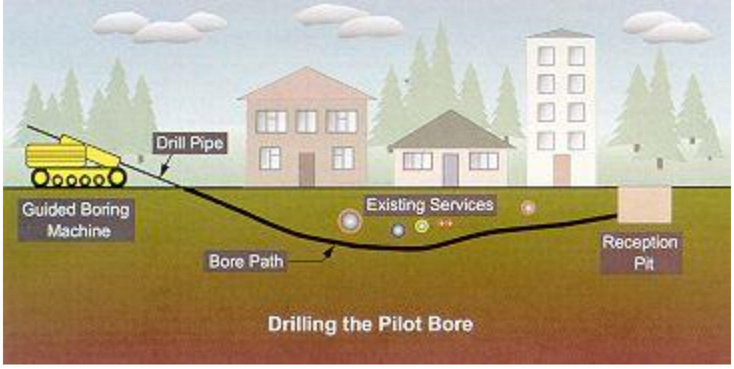
## 2. METHODS

Most, but not all, HDD machines use a fluid-assisted drill head that is pushed through the ground on the end of a string of drill pipes. Inmost softer ground conditions, the drill head is usually angled so that constant rotation of the drill string produces a straight bore, whereas keeping the head in one position causes the line to deviate. In harder ground conditions and rock a different approach may be necessary (see later).

A sonde or beacon is usually built into the head or fixed close to it in a housing, and signals emitted by this are picked up and traced by a receiver on the surface, so allowing the direction, depth, and other parameters to be monitored. These are commonly known as 'Walk-over' systems. Many of the more recently developed walkover guidance systems also now have the capacity to 'capture' sonde signals in situations where no direct access is available immediately above the transmitter. This 'remote guidance' capability was developed to maintain bore trajectory in circumstances where access to the bore head was either impossible due to the geography of a site (river crossings for example) or simply too dangerous to allow operator access such as under the traffic lanes of open motorways or beneath operating railway lines.

Hard-wire guidance systems are also used, with the cable running through the drill string, particularly in cases where the bore path cannot readily be traced on the surface (across rivers, for example) or where the depth of the bore is too great for accurate location by radio-frequency methods. In addition to these hard wire systems, there are Guidance-assist systems which are used to create a localised magnetic field in the area of the bore to override the natural magnetic and electrical fields in areas where metallic structures or in-ground features would interfere with the normal signals of the transmitter sonde. By overriding the naturally occurring fields, transmission signals can be separated out to give a more accurate guidance system. There are also location systems which use magnetometry.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.




A schematic of the horizontal directional drilling process.

A Bentonite/water mix is often used as the drilling fluid or 'mud', which carries bore debris out of the hole in suspension. This may be filtered through a recycling system for recirculation to minimise product usage and cost. On completion of the pilot bore, the thixotropic mud stabilises the hole ready for back reaming. In some circumstances, where ground conditions warrant or bore parameters dictate, polymer additives are used with water and/or Bentonite to create the drilling mud. The service pipe or duct, generally polyethylene or steel, is drawn in behind the final reamer as the original bore is enlarged.

In the case of larger HDD machines, much of the work is done by the rotation of the drill string, and the torque of the unit is as vital a statistic as the axial thrust and pullback. As with smaller rigs, it is normal practice to drill a smaller pilot hole, and then to back-ream to the required diameter while pulling in the conduit behind the reamer, using a drilling fluid to assist the cutting operation and to lubricate and cool the cutting head. The fluid may also power a down-hole 'mud-motor' for cutting rock and other hard formations, in which case higher fluid flow rates are necessary. Bent sub assemblies may be used to provide the steering requirement in harder ground with the drill bit being separately rotated to provide the ground cutting.

Some systems are designed for dry operation without the use of large quantities of water or drilling fluids. These are simpler to operate, create less mess and do not require as much on-site equipment, but there may be restrictions on the sizes that can be installed and on the ground conditions that the machines can cope with.

Another feature that is available which can have significant application where ground conditions vary across the bore path is the use of percussive action to complement axial force and rotation. This can be achieved either with a percussive hammer at the boring head, or by generating the percussion at the machine on the surface and transmitting it along the drill string. Either way, this can improve significantly the ability of HDD machines to punch through difficult ground or hard inclusions.

Return To Overview ▲

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

3. DRILLING MACHINES - GENERAL

Manufacturers throughout the world are numerous and offer a variety of equipment, ranging from compact rigs for small diameters and short lengths, to very large machines capable of installing well over a kilometer of large diameter pipes. An equally extensive ranges of bore guidance systems; drill heads, reamers and accessories are also available.

A surface-launched horizontal directional drilling rig. *Picture courtesy of Tracto-Technik.*

There are two broad categories of machine - surface-launched and pit-launched. Surface-launched rigs are often track-mounted and can be moved into position under their own power. Whilst they do not require start or reception pits to install the new pipe, excavations are nevertheless required to make the connections at each end. Assuming that these connecting pipes are at some depth below ground, the first few meters of new pipe may be 'wasted' in drilling down to the required depth.

Pit-launched machines require an excavation at each end of the bore, but may be operated in restricted spaces. Some of the more compact machines can work from an excavation only slightly larger than that needed to make the joint after installation. Pit launched machines are generally intended to drill fairly straight, and often use stiffer drill pipe than surface launched systems, which may limit their ability to steer around obstacles. The dimensions of the excavation also restrict the length of individual sections of drill pipe, and this may influence the speed of installation and the cost of the drill pipe. In recent years however the smaller end of the surface launch rig market has created a range of machines that are now often used where pit-launch rigs would usually be the main choice.

A pit-launched horizontal directional drilling rig. *Picture courtesy of Tracto-Technik.*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

## 4. FLUID-ASSISTED BORING

There are two essential features of any guided boring machine. The first is a powered rack, which pushes the drill string through the ground to bore the pilot hole, and then pulls it and the product pipe through the bore during the backreaming operation. Typically, the inclination of the rack on a surface launched rig can be adjusted between about 10° and 20° to the horizontal. The second feature is a motor and drive system to rotate the drill string (together with the attached bore head or back-reamer) and provide rotational torque.

Pit-launched machines are fixed in position within the launch pit, using the rear and front faces of the excavation to provide reaction to the thrust and pullback forces. Surface-launched rigs have some form of stake-down system to anchor them to the ground. On the more sophisticated machines, the stake-down system may be hydraulically powered.

Some surface-launched machines are self-contained, having on-board mixing tanks and pumps for the drilling fluid, together with associated power supplies, valves and control systems. Alternatively, separate fluid mixing and pumping units can be provided. The fluid is pumped through the hollow drill string to the bore-head, and returns through the space between the drill string and the walls of the bore. The fluid, together with the excavated material mixed with it, is usually pumped into a recycling unit for separation and re-use.

Drilling rigs, especially surface-launched machines, may incorporate an automatic drill pipe loading system in which the lengths of drill pipe are contained in a ‘carousel’ or on-board storage rack. These automatically add or remove drill pipe from the drill string, as boring or back-reaming progress. This usually operates in conjunction with an automatic vice arrangement which screws the drill pipes together or unscrews them during back-reaming. Automatic pipe handling has become increasingly common, even on smaller machines, since it speeds up installation, improves safety and reduces manpower requirements.

The pullback capacity range of surface launched HDD machines have widened immensely since the introduction of the first rigs some 25 years ago. Thrust and pull back capacities go from 3.5 t for the smallest of rigs, up to 600 t on some ‘Mega-Rigs’, with torque capacities up to almost 50,000 Nm, depending on speed of rotation. This range makes it possible, under the right conditions, to install pipe diameters from 50 mm with the small rigs, up to 1,500 mm with the largest rigs. Installations are possible up to 1,500 m under the right conditions with the larger rigs although most are between 50 and 500 m.


A fluid-assisted rig.
*Picture courtesy of Vermeer.*

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work.

A larger capacity HDD rig. Picture courtesy of Herrenknecht

The capabilities of HDD machines vary considerably according to the type of ground through which they are drilling. In general, homogeneous clays are the most favorable soils, whilst sand can present problems especially if it is below the water table or is not self-supporting. Gravel can be penetrated at the expense of accelerated wear to the bore-head. Standard machines without percussive action or mud motors are generally unsuitable for penetrating rock or hard inclusions, and the bore head will either come to a stop or be thrown off line if such obstacles are encountered. However, mud motors, powered by the drilling fluid, can be used to drive rock-cutting heads, and this technique may be used with some of the more powerful rigs. Twin shaft drill rods can also be used to create a rock boring assembly where the inner drill stem rotates the rock cutting bit and the outer stem provides the steering capacity. This system can remove the need to have large quantities of drilling fluid available to drive a downhole motor.

Another way of improving performance in hard ground is to use percussive action in conjunction with forward thrust and rotation. Percussion may be transmitted through the drill string by a hammer integrated into the drilling rig, or in some cases by a pneumatic hammer at the bore-head. Percussion allows improved penetration and directional control in stony soils or weak rock, but is not intended for drilling through solid rock or large masses or very hard material such as concrete.

The choice of back reaming tools and accessories is also very wide, and most have particular design features that are claimed to enhance performance. Most reamers are bullet shaped with an arrangement of tungsten carbide teeth and fluid jets. The rear of the reamer has a coupling to which a towing head can be attached for pulling in the product pipe. Special designs are available for difficult ground conditions, including hole-openers for reaming in rock.

Return To Overview ▲

## 5. FLUID JET BORING

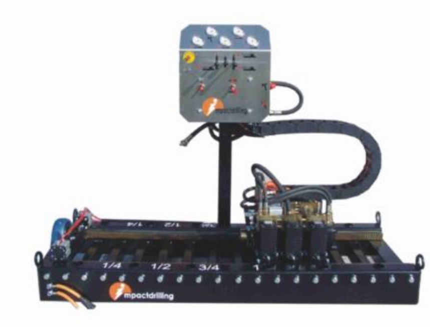
Using a basic operation that is exactly the same as with Fluid-Assisted Boring, Fluid Jet Boring has but one basic difference from the system outlined above. In this technique instead of utilising a mechanical cutter for ground excavation at the boring head, a series of high-pressure fluid jets are used. The jets may be of water or a drilling fluid mix. The fluid is passed down the drill string under a pressure much higher than that used for Fluid-Assisted Boring, and is projected forward out of the end of the angled cutting head in such a way as to dislodge the ground ahead of the drill string. The angled head allows for steering adjustments in the same way as with Fluid-Assisted Boring. This system is today far less widely used than Fluid-Assisted Boring and tends to be more applicable to softer ground suited to excavation by the high pressure jets.

Return To Overview ▲

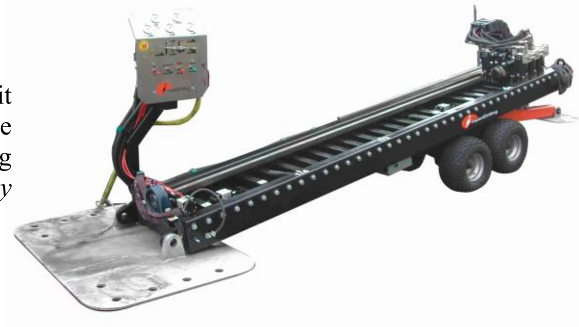
6. DRY BORING

Whilst most guided boring machines use a drilling fluid to lubricate the bore-head, convey waste material back to the launch pit and stabilise the bore, some systems are designed for dry operation. Both surface-launched and pit-launched versions are available, and Dry Boring machines tend to be more compact and simpler than most fluid-assisted rigs.

Instead of relying entirely on thrust and rotation generated at the rig, Dry Boring machines use a high-frequency pneumatic hammer at the bore head to penetrate and compact the ground for the pilot bore. In this respect, the concept is not unlike an impact mole on the end of hollow drill pipes which also act as the pneumatic feed. As with fluid-assisted systems, the chisel head in front of the hammer is angled, allowing the bore to be steered by stopping the rotation at a particular orientation.



Examples of both pit launched and surface launched Dry Drilling rigs. *Pictures courtesy of Impact Drilling Ltd.*



For small diameter pipe, duct or cable installation (up to about 65 mm diameter) using dry methods, a cone-shaped reamer with tungsten-carbide cutting teeth may be connected directly to the drill rods. The expander is fitted with air jets, fed through the drill string, and high velocity airflow helps to clean out the bore during back reaming. The expander is rotated and pulled back to enlarge the bore, with the pipe attached to the rear using a swivel connector and some form of towing head.

For the dry installation of pipe diameters up to 250 mm, a pneumatically powered reaming hammer may be used, again with the pipe string attached to the rear of the device by means of a swivel. The percussive effect of the reaming hammer, rather than the pullback force of the machine, is the main agent in expanding the bore, and no rotation is required during back reaming. As with the pneumatic hammer used for the pilot bore, the air supply for the reaming hammer is conveyed through the drill string.

An intermediate technique between Fluid-Assisted and Dry Boring is to incorporate a water/polymer mist lubrication system into the airflow of a Dry Boring machine. This helps to moisten and loosen the soil, and can increase productivity in dry soil conditions. Water/polymer mist lubrication can be used during both pilot boring and back reaming.

Both Fluid-Assisted and Dry Boring methods have their merits in appropriate conditions. Whilst Fluid-Assisted boring has greater versatility in terms of ground conditions and maximum diameters, it requires more equipment and involves dealing with mud-filled excavations and the disposal or recycling of materials. Smaller diameter Dry Boring is essentially a displacement technique, and should perhaps be described as ‘Guided Moling’. As such, it is best suited to compressible, self-supporting soils, and may not be appropriate for sands and gravels at bore diameters above about 75 mm. The risk of surface heave should also be considered, especially in granular soils.

Larger capacity Dry Drilling rigs have been introduced, with the capability to bore and install pipelines of similar dimensions to Fluid-Assisted machines.

Return To Overview ▲

7. DRILL PIPES

Considerable physical demands are made of the drill pipes. They must have sufficient longitudinal strength to withstand the thrust and pullback forces, enough torsional stiffness to cope with the rotational torque of the machine, and yet be flexible enough to negotiate changes of direction in the course of the bore. They should also be as light as possible to facilitate transportation and handling, whilst resisting damage due to abrasion and scoring.

The length of individual pipes depends on the type of drilling machine and the space available. Typically, surface launched rigs will use pipes up to 4 or 5 metres long, whilst drill pipes for pit launched machines are often between 1.0 and 1.5 metres in length. Screw joints are most commonly used, although bayonet fittings are found with some systems, though rarely.

Most drilling machine manufacturers offer their own proprietary brands of drill pipes, and there are also specialist companies producing a variety of alternatives. Obviously, it is important to ensure that the drill pipes are wholly compatible with the drilling machine, especially if the rig incorporates an automatic drill pipe handling system, and also with other components such as bore-heads, sondes, and reamers.

Return To Overview ▲

8. DRILLING FLUIDS (see also subsection - SPOIL HANDLING AND LUBRICATION FLUIDS)

Depending upon its formulation, the drilling fluid may have several functions:-

a. To lubricate and/or cool the cutting head and reduce wear.
b. To soften the ground so that it is easier to drill through.
c. To convey excavated material in suspension back to the launch pit.
d. To stabilise the bore prior to back reaming.
e. To lubricate the product pipe during back reaming and insertion.
f. To power mud motors for drilling through hard ground.

The simplest drilling fluid is water, and it may be unnecessary to use anything more sophisticated for short bores of small diameter through good ground.

A mixture of Bentonite and water is the most common type of drilling fluid or ‘mud’. Bentonite is a type of clay with thixotropic properties, meaning that it remains fluid as long as it is being pumped or agitated, but forms a gel if allowed to stand. If agitated again, it reverts to a fluid. The material therefore acts as a lubricant and carrier during the drilling operation, but solidifies to stabilise the bore once drilling stops. During backreaming, the mud helps to provide lubrication between the product pipe and the walls of the bore, and reduces soil regression and friction.

In addition to simple water/bentonite fluids, there are polymer-based materials and a wide range of additives, which are used to tailor the properties of the drilling fluid to suit the soil conditions and the nature of the project. For example, the viscosity should be low enough to flow through the system at reasonable pressures, but sufficiently high to prevent significant loss into the ground.

The formulation of drilling fluids is a complex science in its own right, and one which plays a major part in the success of projects. Most manufacturers of drilling machines have their own recommendations on the most suitable fluids for particular applications, and advice is also available from the manufacturers of the ‘mud’ materials. This is an area where specialist guidance should be

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

sought, especially when dealing with difficult ground conditions. The design of mixing, pumping, filtration and recycling plant is also a major consideration, especially for large-scale projects, and again advice should be sought from experienced contractors or manufacturers.

Return To Overview ▲

## 9. TRACKING & GUIDANCE SYSTEMS

Most HDD techniques, other than some short-distance pit-launched applications, rely on accurate bore location and guidance systems. The capability of tracking devices has improved considerably since the early years, with advances in electronic technology, and a high degree of accuracy is now achievable.

**A walkover system tracking an HDD bore.** *Picture courtesy of Ditch Witch/ Subsite.*

There are several types of tracking system. The most common, known as 'walk over' systems, are based on a sonde or beacon contained in a specially designed housing behind the bore-head. This emits a radio signal, which is picked up by a receiver on the surface. In addition to giving the position and depth of the bore-head below ground, the data transmitted will often include the inclination of the drill bit, the orientation of the head, beacon battery status and beacon temperature. It is common for this information to be relayed to a satellite receiver at the drilling machine, so that the rig operator has direct access to the data and can make any necessary steering adjustments accordingly.

Walk over systems are in many respects similar to pipe and cable detectors. The receiver is moved to a position which gives the strongest signal, at which point it should be directly above the beacon. Their main limitation is the need to gain access to the surface directly above the bore-head, which may be difficult or impossible if the line runs under a building or beneath a body of water. This may be overcome by using either a 'hard wire' guidance system (see below), a beacon containing an on-board electronic compass or a system with a remote tracking capability.

Several walk over systems have been developed, either by OEM or specialist manufacturers, which to a significant extent allow the systems to be utilised even where no direct access above the bore head is available through geographical or safety reasons. The Surface antenna is placed in fixed position on the ground where the final walk over measurement is taken, often orientated so that it aims along the bore route. As the bore head sonde moves away from the antenna, location information pertaining to left or right of bore alignment and bore head pitch can be obtained over distance of up to almost 20 m from the last measured walkover point. An experienced operator

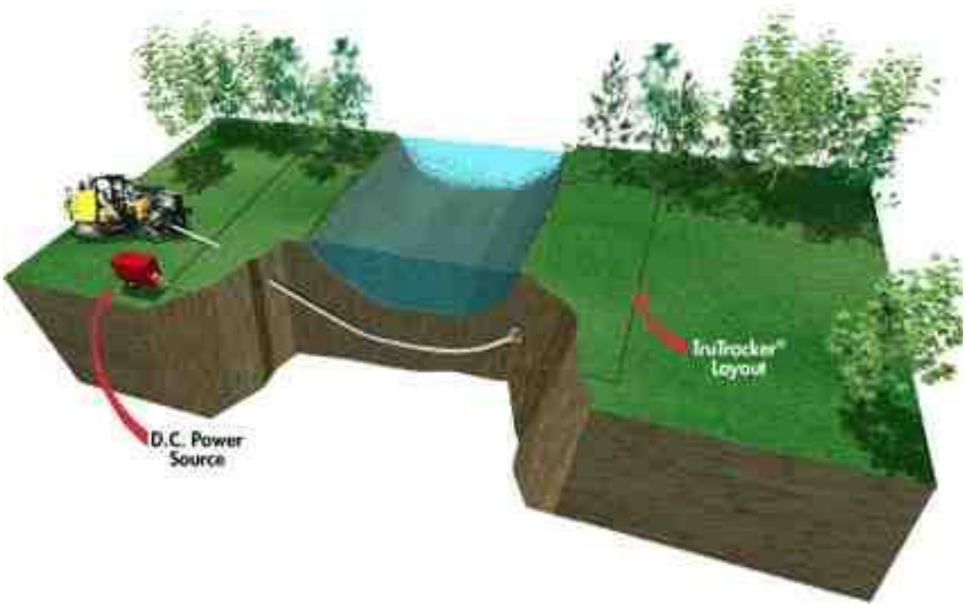
Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

utilises this information to estimate the bore head position in the ground so that, although no direct depth measurement is possible, a good estimate of bore position, and therefore any steering correction, can be made. Once the bore head passes out of range of the antenna, if conditions are such that the surface antenna can be moved to the arrival end of a bore close to the required exit point, the system can be used to guide the advancing bore head towards the exit point, until it is in a position where operators can re-establish the exact position using the full walk over capability.

'Hard wire' systems use a cable running through the drill string to transmit data from the beacon to the control console. Whilst the cable is an added complication during extension of the drill string, it allows bore tracking across any terrain without relying on the transmission of radio signals, and can also be used in locations affected by electromagnetic interference.

When initialised to a predetermined azimuth heading, a compass beacon notifies the operator when the bore-head has deviated from the intended bore path. The left/right deviation information is sent to a tracking receiver and is displayed in a format similar to pitch and roll information. The operator does not have to be above the beacon or on the intended bore path, and, in some cases, data can be received at distances of over 300 metres from the beacon.

Because of the operating environment, beacons must be extremely durable and resistant to shock and vibration. This applies particularly in the case of drilling rigs with percussive action, where some form of shock-absorption mechanism is likely to be required.




**Artificial magnetic field set up in high interference areas for HDD hard wire guided bores.** *Picture courtesy of Inrock Drilling Systems*

Where high electromagnetic interference is likely to be encountered, there are systems that use a surface loop/antenna to generate its own electromagnetic environment on a localised basis. Operating a hard wire system within this system enables accurate bores to be completed with a high degree of accuracy in the most electronically 'noisy' environments.

To avoid subjecting electronics to severe dynamic loading, a location and guidance system based on magnetometry is used with dry guided boring machines, which employ percussive hammer action. Permanent magnets are housed in a section of the pilot hammer, and a magnetic field is created as the hammer rotates. The strength and fluctuation of this field is detected by magnetometers on the surface, and a computerised processing unit translates this data to give the location, depth and roll angle of the bore head. As with radio beacons, the tracking information can be relayed to the drill operator's console.

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

10. ANCILLARY EQUIPMENT

Although most attention is focused on major items of equipment, there are numerous accessories and ancillaries that play an important part in the success of a guided boring or directional drilling project.

Various types of towing heads for polyethylene pipes are available, including pressure tight heads and versions aimed specifically at directional drilling. One function of directional drilling towing heads is to prevent the ingress of drilling fluid or debris into the product pipe, which may be an important consideration for potable water pipes that have to be sterile.

Swivel connectors are an essential component during the backreaming and pipe-pulling operation, and should be designed to prevent the entry of mud and debris to the bearings. Models are available with capacities from less than 5 to over 200 tonnes.

Some contractors use 'breakaway connectors' to protect the product pipe. The connectors have a series of pins designed to break under a predetermined load, and are set according to the permissible tensile load on the product pipe. Not only do breakaway connectors reduce the risk of inadvertent damage, there is also a psychological effect on operators who are aware that the permissible pulling force cannot be exceeded, and therefore resist the temptation to increase the load for higher productivity.


Other important ancillary equipment may include butt-fusion machines for jointing polyethylene pipe lengths, pipe support rollers and cable pullers.

Return To Overview ▲

11. BORE PLANNING SYSTEMS, SAFETY DEVICES AND OTHER CONCERNS

As well as the basic design and manufacture of HDD systems, machine manufacturers have also been developing bore assist systems and new applications for the technology.

One of the most useful, as a planning tool for engineers using or considering using HDD for an installation, is the Bore Planner software that has been developed. This software enables engineers to put the parameters of a bore into a computer. The Bore Planner program will then produce a 'best fit' route and depth, which can be used as the blue print for the bore in the ground.

Data acquisition software has also been developed, which enables steering data to be utilised to complete an 'as-built' drawing for the contractor and/or the client, based on the actual pilot bore run. This information provides not just the plan position of the new installation, but also the depth information that is becoming increasingly important in high-density buried service areas.

Whilst HDD has become well established as a viable construction method one of the areas where the technology can still being improved is this sort of documentation of a bore. This is especially important where sometime there is a need to convince design and consulting engineers to specify HDD when appropriate. This is where education and properly documented information will go a long way towards assisting engineers and municipalities in justifying the use of HDD.

With the ability to provide as-built plans for the bore route, there has also been an increasing demand to show that during installation pipes have not been overstressed during the pull-in, in a manner which may affect future serviceability and performance. To this end, developments have been made which allow a load and pressure monitoring device to be attached to the assembly during pullback which allows for real time monitoring of the pulling loads on a product pipe and drilling fluid pressure during installation. The primary benefit of this system is the ability to maintain the integrity of the product pipe (it is not being overstressed) and the monitoring of drilling fluid pressure which can be used to minimise damage to road ways or other above or below ground structures that hydraulic pressure could distort, for example by blow-out at surface. Additional benefits include hard copy reports of the loads and pressures measured during the installation for after the fact analysis.

From a safety point of view, several OEMs now also provide with their machines, either optionally or as standard, Safety Cut out or Lock out systems which protect operators when working on the machine. As well as the general use of 'Faraday' cages to protect operators in the event of a cable strike, safety systems now exist that provide for power shut down, should the operator not remain seated at the controls. Other systems have been developed which allow the machine to be locked out, to ensure that when work is being carried out on the pipe side of a bore (a position often out of line of site of the drilling rig), the rig cannot be started or operated without the correct clearance signal being given.

Increasing emphasis on site and workforce safety has in recent years also led to an on-going discussion about exposure to rotating parts, across industry not just in the trenchless sector. This has led to questions being raised about the location of safety barriers between the rotating drill stems of HHD rigs and the workforce or passing public. Whilst in some areas this discussion is ongoing , manufacturers are aware that they may need to modify machine design to accommodate potential new rules about covering rotating parts during the drilling and pullback operations with contractors being increasingly aware that sites may need to have barriers to ensure no encroachment of pedestrians during machine operation.

New applications for HDD technology include Pipe Reaming, a class of pipe replacement technology which utilises the drill string, and pulling power of an HDD rig, to draw a reaming head through an established pipe line to, in effect, burst the old out and replace it with a new one. (see On-Line Replacement Section).

To assist the installation of a pipe that has become stuck in a bore during pullback, a system has been developed which utilises an impact hammer on the pipe-side end of the pipe. The reciprocating action of the hammer blows add impetus to the pipe string in the ground which, when added to the pullback force of the drill rig, overcomes the obstruction or restraint which prevents the pullback being completed. (See Impact Mole and Rammers Section).

The range of product or casing pipe available to operators for installation using HDD has also been expanded. The most significant development has been that of the sacrificial skin pipe, which, although developed largely for pipe burst installations, has also found a market in the HDD sector, particularly in hard, ground conditions where cobbles and rock could damage the new pipe during installation.(See On-Line Replacement Section).

Return To Overview ▲

## 12. SUMMARY

1. HDD can be used for the trenchless (or minimum excavation) installation of pipes, ducts and cables in most diameters and over distances of over a kilometre or more.
2. Both surface-launched and pit-launched drilling machines are available, the choice depending on the nature of the project.
3. Machines range from compact rigs suitable for small bores and operation in restricted spaces, to extremely large units designed for large diameter, long distance crossings.
4. Most guided boring machines use a drilling fluid, which lubricates and stabilises the bore, and also conveys the excavated material in suspension. Some rigs are, however, designed for dry operation, and may offer benefits depending on the bore diameter and the ground conditions.
5. Drill pipes should be chosen carefully to provide the right combination of strength and flexibility. The maximum length of individual drill pipes depends on the type of machine and the operating space.
6. The formulation of the drilling fluid or ‘mud’ is important, especially in difficult soils, and advice should be sought from specialists where necessary.
7. The choice of guidance system depends on the type of machine and also whether access is available for ‘walk over’ tracking. Radio, hard wire and magnetic systems are available.
8. Attention should be paid to the selection and maintenance of ancillary equipment such as towing heads and swivel connectors, whose performance can have as much effect on the outcome of the job as the more conspicuous items of equipment.
9. Bores can be planned in advance and monitored through the installation process to ensure documentation is fully available.

Return To Overview ▲

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

| INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY | **TRENCHLESS TECHNOLOGIES RESOURCE CENTRE** | |
|---|---|---|
| | TRENCHLESS TECHNOLOGY GUIDELINES | THIRD EDITION |
| | SPOIL HANDLING AND LUBRICATION FLUIDS | LAST UPDATED JULY 2009 |

1. OVERVIEW

Boring and Drilling Fluids, known widely as Slurries or Muds, and lubrication fluids seem, to most, to be the dirty side of their respective operations. Although water can be used on its own, most fluids are based on a mixture of water and bentonite (a very fine type of clay with thixotropic properties, meaning that it remains fluid as long as it is being pumped or agitated, but forms a gel if allowed to stand). These fluids have a vital role to play in both microtunnelling operations and in the HDD boring sector for a variety of different and sometimes similar reasons. The mud/slurry is not always bentonite based. Over many years several synthetic polymers and other natural additives have been developed and/or brought into use that mimic or compliment the use of bentionite in the fluid mixture, or give specific properties to the fluid that are called for, due to ground or other site variations on individual projects.


Various bentonite types and additives are available for boring and drilling fluid formulation. *Picture courtesy of Baroid Industrial Products*

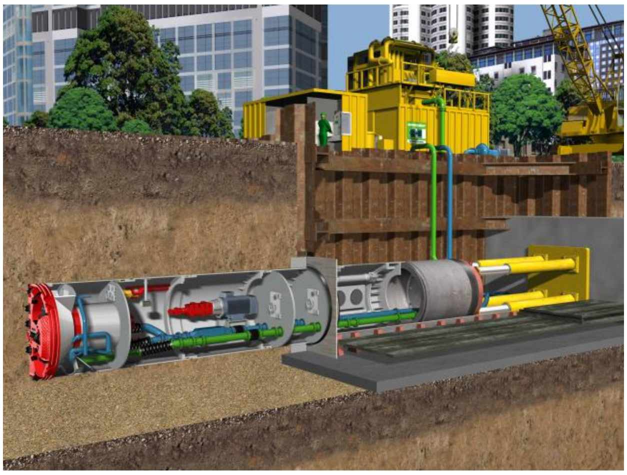
2. APPLICATIONS

a. Pipejacking and Microtunnelling

The main purposes of bore slurry in the microtunnelling sector is often two-fold. First, in the correct mixture, a slurry can provide face support during the excavation process, ensuring that the face remains open, and/or that there is no loss of ground that might cause problems for the operator in terms of machine control or subsidence at surface, should too much ground be removed by the tunnelling system. Second, the slurry can act as the spoil transport and removal

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

medium, taking excavated spoil away from the face at a rate suited to the advance capabilities of the tunnelling system.



A typical re-circulating slurry system arrangement for a microtunnelling machine. *Picture courtesy of Herrenknecht.*

More often in recent years, the volume of slurry used per project has been reduced by the introduction of slurry recycling plant, which removes spoil from a circulating slurry, reconditions it to the specifications required, and returns it to the face for reuse.

There is third application for slurry in the pipejacking and microtunnelling field, in that it can be used as a lubricant. The fine clay base of most slurries make it an excellent material for reducing friction losses between the pipe being jacked and the surrounding ground, and it is often injected into the annulus between pipe and ground, specifically for this purpose (see below).

A typical microtunnelling spoil separation and fluid recycling set-up. *Picture courtesy of Derrick Corporation*

Return To Overview ▲

b. Horizontal Directional Drilling

In HDD operations the drilling fluid, or Mud as it is more commonly known, has a variety of functions depending on the circumstances in which it is used. These include: To lubricate and/or cool the cutting head and reduce wear; To soften the ground so that it is easier to drill through; To convey excavated material in suspension back to the launch pit; To stabilise the bore during pilot hole boring and prior to and during backreaming; To lubricate and support the product pipe during backreaming and insertion; and to power downhole mud motors for drilling through hard ground. The mud formulation is varied according the job, or jobs, it has to do.

**A typical HDD fluid recycling set-up.** *Picture courtesy of Kem-Tron Inc*

These muds are, more often than not, recycled through spoil cleaning system, to reduce the quantity required per project, as with pipejacking and microtunnelling.

Return To Overview ▲

c. Muds As Lubricants

The two greatest forces that need to be overcome in jacking a pipe are the weight of the pipe string and the friction between the surface of the pipe and the ground, as the pipe moves through the bore. Similarly this is the case for a pipe string being pulled in during an HDD operation. Friction increases with pipe diameter, as a greater surface area of pipe is presented to the internal surface of the bore. The problem of friction is most commonly addressed by using pipe of the smallest acceptable diameter, and by lubrication. In the earliest days of pipejacking it was sometimes left to brute force to overcome the total resistance by simply installing a larger capacity jacking frame. This could lead to early pipe failures as the maximum load bearing capacity of the pipes was exceeded in difficult conditions. Similarly, early HDD bores sometimes failed because the use of simple pulling force on a pipe caused failure, as friction loads increased above the level of the tensile strength of the pipe material.

The introduction of lubrication using a bentonite mud, or combination bentonite/polymer mixture, can overcome most of the loading problems. The mud mixture is designed to work efficiently in the expected ground conditions. A simple formulation can be used where the lubricant will not be absorbed or drain away into the surrounding ground.

In more difficult conditions, where loss of lubricant can be expected, or where ground pressures are likely to be high, the lubricant can be modified to reduce loss and/or to assist in providing ground support throughout the duration of a pipejack or pipe pull-in. For pipe jacking, the lubricant is conveyed by pipes installed within the main pipe string, and is injected through ports drilled through the pipe wall, often pre-drilled during the pipe manufacture, as man entry is not permitted in many cases with microtunnelling operations. Each injection port may be fed by a separate lubrication line. Injection is controlled either manually from the operator’s station, or by means of a computer-monitored system through a central distribution manifold. The latter system is increasingly popular, and allows measured amounts of specific lubricants to be added at the correct position, at an optimum pressure along the pipe string, as the ground varies and the pipe string moves forward. Computer monitoring often increases the efficiency of lubrication by minimising over-lubrication at any one point, bearing in mind that lubricants can be expensive. On smaller diameter, often shallower, pipejacks or microtunnels, this can be a significant advantage as it minimises surface heave or loss of lubricant through cracks to the surface.

For HDD, the lubrication comes simply from the flow of mud through the bore, as pipe pull-in occurs. The formulation is vital here to ensure bore stability, pipe support and lubrication.

On many projects the use of the correct lubrication materials and techniques can bring about a considerable reduction in jacking/pull-in loads and ground support problems. It may also allow the use of a smaller jacking frame or drill rig, thus minimising the size of the drive shaft or start pit, helping to reduce the overall cost of the project. Using modern lubricants and installation techniques, it may be possible to install up to 1,000 metres of pipeline in a single drive.

Return To Overview ▲

3. SPOIL REMOVAL/GROUND SUPPORT IN MICROTUNNELLING

Although used sometimes in Pipejcking operations, slurries are more often found in microtunnelling systems. For microtunnelling, specific properties may be required for either face support or spoil removal, but often the systems work in a very similar way to those used for HDD, just on a larger scale, so, to save repetition, see below for more detailed coverage. The only real difference between microtunnelling slurries and HDD fluids is the carrying capacity. Microtunnelling tends to produce larger spoil pieces, so the fluid requires greater carrying capacity therefore systems tend to be larger and more powerful to move the ultimately heavier fluids around the recycling system. Volumes used also tend to be high, so recycling is often the only economic solution. Most microtunnelling slurry circuits operate in closed circuit with both feed and return flows passing through a pipeline system. In HDD an open circuit may be used where conditions and pumping arrangements allow.

Return To Overview ▲

4. BORING FLUIDS FOR HDD

There are two aspects of HDD drilling fluids that should be considered, the mixture and handling of the fluid in operation. In some circumstances HDD fluids can be used in open circuit where no cleaning or collection for recycling is done, but environmental pressures in recent years have seen their use in this manner almost disappear. The expense of using fluids only once has also helped to reduce this type of use, as it has on the increasingly frequent larger diameter bores where usage volumes can become very high.

A. Mixtures

The formulation of drilling/boring fluids is a complex science in its own right, and one which plays a major part in the success of projects. Most manufacturers of drilling machines have their own recommendations on the most suitable fluids for particular applications, and advice is also available from the manufacturers of the materials. This is an area where specialist guidance should be sought, especially when dealing with difficult ground conditions. To assume that simply throwing bentonite mud at a problem will solve it, is a situation to be avoided – seek advice – this cannot be stressed heavily enough!

B. Handling

The design of mixing, pumping, filtration and recycling plant is also a major consideration, especially for large-scale projects, and again, advice should be sought from experienced contractors or manufacturers.

In short, most systems rely on a combination of agitators, stirring devices or venturi jets to mix the bentonite/polymer/water and any other additives together in the mixing tanks. Normally these mixtures have to be agitated for a length of time to allow full ‘hydration’ of the solid particle with the water. Once mixed, an arrangement of slurry pumps passes the fluid from the mixer tanks to storage tanks, where they are continuously agitated to maintain the fluids characteristics. When required, the fluid is then passed into the boring system using special 'slurry' pumps, normally by pumping down the hollow drill rod to the cutting head (or through a circulating pipeline within a microtunneller system). The fluid then passes through the head, cooling it if necessary, picking up spoil from the face of the bore, returning it to the launch area by passing along the annulus between the drill rod and the bore wall. If designed to do so, the properties of the fluid will help support the bore wall, and/or form a fluid 'skin' at the bore wall preventing loss of fluid into the surrounding ground.

For both HDD and microtunnelling, on return to surface, the fluid is collected and passed through a specially designed spoil separation system, comprising a series of mesh sieves and hydrocyclone solids separators that remove the larger particles from the fluid down to the designed size cut-off. The fluid, if necessary, is checked and re-formulated to its required specification and returned to the storage tanks for re-use down hole.

Many countries have over the past few years introduced regulation as to the use and disposal of boring and drilling fluids. Users should make themselves fully aware of these local requirements. Environmental controls are increasingly a part of the fluid industry's major activities.

## 5. SUMMARY

1. Fluids have a vital role to play in both Microtunnelling and HDD operations in terms of bore maintenance, ground support and spoil removal.
2. The design of a fluid and maintenance of it operating specification can mean the difference between success or failure of a project.
3. Design of fluid is very specialised for many circumstances and advice should be sought at an early stage from machine manufacturers or fluid specialists.
4. Similarly for fluid handling – these systems are very complex and need to be set up properly to achieve their best efficiency – expert advice should be sought.
5. New regulations are appearing in many parts of the world – make yourself aware of your local responsibilities in respect of fluids and their disposal.

Return To Overview ▲

Bibliography:

1. Hardrock Tunnel Boring Machines by: Maidl, B., Schmid, L., Ritz, W., Herrenknecht, M. Publisher: Ernst & Sohn
2. Practical Guideline for the Application of Microtunnelling Methods by: Prof. Dr.-Ing. Stein & Partner GmbH Publisher: Prof. Dr.-Ing. Stein & Partner GmbH
3. Technical Guidelines Horizontal Directional Drilling (DCA) by: Drilling Contractors Association (DCA-Europe) Publisher: Drilling Contractors Association (DCA-Europe)
4. HDD-Installation Guidelines, CD-ROM by: NUCA Publisher: NUCA
5. HDD-Practice Handbook by: Dr. H.-J. Bayer Publisher: Vulkan Verlag
6. Horizontal Directional Drilling by: David A. Willough Publisher: McGraw-Hill Professional Publishing
7. Pipeline Design for Installation by Horizontal Directional Drilling Publisher: American Society of Civil Engineers

Disclaimer: This document is provided for historical reference only. This guideline has been replaced by the new Trenchless Technology Charts and Descriptions on the website. Be aware that some links may no longer work. Use this information at your own risk.

8. Horizontal Auger Boring Projects Publisher: American Society of Civil Engineers

Please contact ISTT – info@istt.com for further information.

Conference Papers: These may be accessed via the TRC Home page. If none are currently available on-line, please contact ISTT – info@istt.com for further information.

If there is any information that you consider to be missing from this Guideline or have seen any information that you feel is incorrect please contact ISTT directly stating the omission or incorrect item. ISTT will endeavour to correct any such omission or error subject to further investigation to validate any such claim. Email: info@istt.com