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	HORIZONTAL DIRECTIONAL DRILLING	NEW VERSION AUGUST 2005

1 OVERVIEW

Horizontal directional drilling or HDD (known also as Guided Boring) techniques 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. 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 drill into the ground at a shallow angle.

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 the two this term and that of Guided Boring.

Surface-launched guided boring machine with integral drill-pipe carousel

Picture courtesy of Tracto-Technik

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 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is attached to the reamer by means of a swivel connector, and is pulled into the enlarged bore as the drill string is withdrawn.

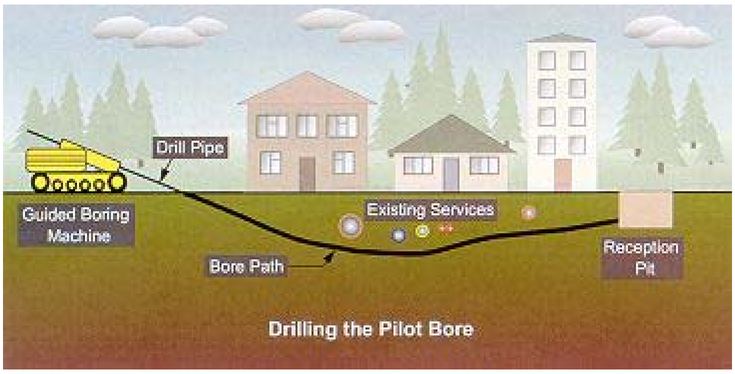
In earlier years, HDD was used mainly for the installation of pressure pipes and cable ducts, where precise gradients are not usually critical, rather than for gravity pipelines which demand close tolerances in vertical alignment in order to meet hydraulic design criteria. However, in more recent years,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

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.

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. 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. A sonde or beacon is usually built into the head or fixed close to it, 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 localized 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.



A Bentonite/water mix is often used as the drilling fluid or 'mud', which carries bore debris in suspension and may be filtered through a recycling system. On completion of the pilot bore, the thixotropic mud stabilizes 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.

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.

An increasingly common feature 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.

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 range of bore guidance systems; drill heads, reamers and accessories is also available.

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 starter 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.

Drilling the pilot bore with a typical surface-launched guided boring machine

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.

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.

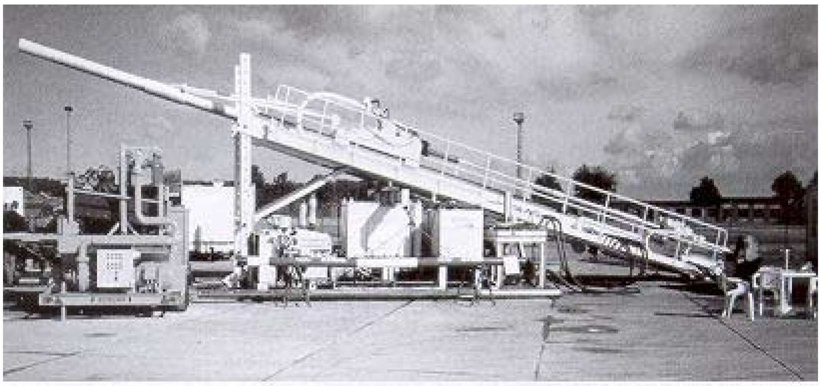
Alternatively, separate fluid mixing and pumping units can be provided. The fluid is pumped through the hollow drill string to the bore-head, and returns through the space between the drill string and the walls of the bore. The fluid, together with the excavated material mixed with it, is usually pumped 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 and are automatically added to or removed from the drill string as boring or back-reaming progresses. 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.

Fluid-assisted rig with automatic drill-pipe handling

Picture courtesy of Tracto-Technik

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 capability now runs between 3.5 t for the smallest of rigs up to 600 t with some of the Mega-Rigs as they are known, and torque capacity available is up to almost 50,000 Nm depending on speed of rotation. This range of capacity makes it possible under the right conditions to install pipe diameters from as little as 50 mm with the small rigs up to as much as 1,500 mm with the largest rigs. Installations are possible over distances of up to 1,500 m under the right conditions with the larger rigs although most installation are between 50 and 500 m.



Large directional drilling rig designed for long-distance crossings beneath major rivers, estuaries, motorways, railways and canals

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. 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. Some machines utilize a double pipe drill rod to enable a rock cutting head to be used for advancing the bore whilst the second rod applies the steering corrections.

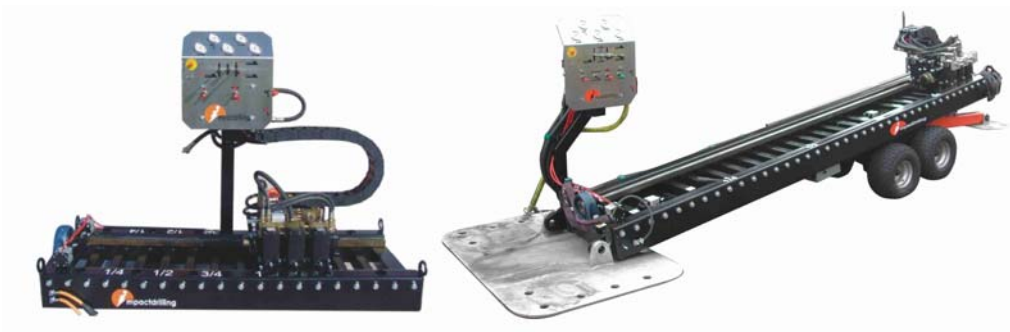
The choice of back reaming tools and accessories is also very wide, and most have particular design features that are claimed to enhance performance. Most reamers are bullet shaped with an arrangement of tungsten carbide teeth and fluid jets. The rear of the reamer has a coupling to which a towing head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

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 that shown above. In this technique instead of utilizing 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 less widely used than Fluid-Assisted Boring and tends to be more applicable to softer ground suited to excavation by the high pressure jets.

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 stabilize 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. 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.

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.

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.

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 stabilize 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 stabilize 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.

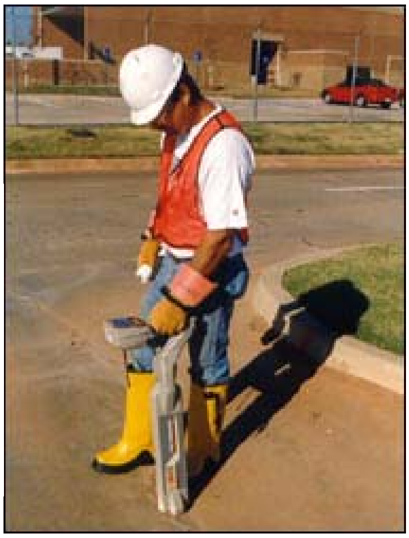
In addition to simple water/bentonite fluids, there are polymer-based materials and a wide range of additives, which are used to tailor the properties of the drilling fluid to suit the soil conditions and the nature of the project. For example, the viscosity should be low enough to flow through the system 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 materials. This is an area where specialist guidance should be 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.

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 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, in that 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.

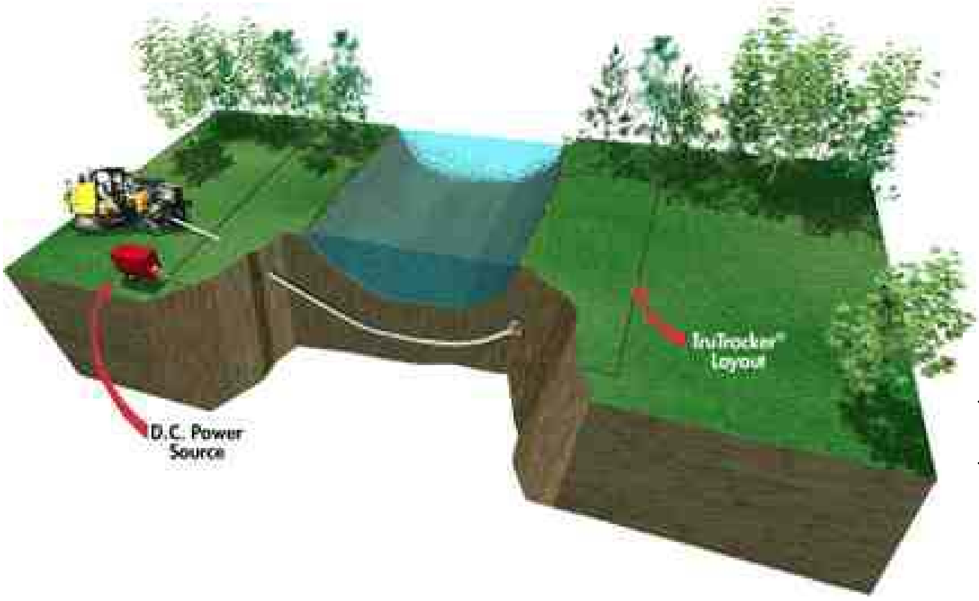
This may be overcome by using either a 'hard wire' guidance system (see below), a beacon containing an on-board electronic compass or a system with a remote tracking capability.

Several walk over systems have been developed, either by OEM or specialist manufacturers, which to a significant extent allow the systems to be utilized 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 utilizes 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 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, 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 initialized 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 localized 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 computerized processing unit translates this data to give the location, depth and roil angle of the bore head. As with radio beacons, the tracking information can be relayed to the drill operator's console.

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, pipe support rollers and cable pullers.

11 LATEST DEVELOPMENTS
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 into a computer the parameters of a bore and the Bore Planner program will 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 utilized 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.

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.

New applications for HDD technology include Pipe Reaming, a class of pipe replacement technology which utilizes 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 Section On-Line Replacement).

To assist the installation of a pipe that has become stuck in a bore during pullback, a system has been developed which utilizes 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 Section Impact Mole and Rammers).

The range of 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 Section On-Line Replacement).

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 stabilizes 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.