ISTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	**TRENCHLESS TECHNOLOGY RESOURCE CENTRE**	
	TRENCHLESS TECHNOLOGY GUIDELINES	SECOND EDITION
	PIPEJACKING AND MICROTUNNELING	NEW VERSION AUGUST 2005

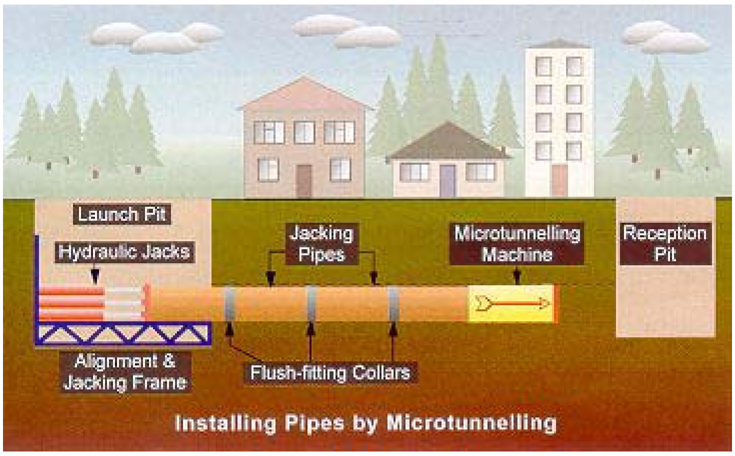
1 OVERVIEW

Pipe jacking 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 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, form the final pipeline once the excavation operation is completed.

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. Microtunnellers often use a laser guidance system to maintain the line and level of the installation, though, as with larger pipejacking installations, both laser guidance and normal survey techniques can also be utilised.

Pipe jacking and micro tunnelling are normally used for main line or trunk pipelines.

Pilot Auger systems are a type of hybrid between a directional drilling system and a 'traditional' microtunnelling system where a drill string is used to bore a pilot hole on a line and level monitored and controlled normally using a laser theodolite aimed at a target situated just behind the boring head. The bore is reamed using an auger chain used to expand the bore after the pilot bore has been completed and the pipe is jacked into position 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.



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. 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 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, alignment systems based on, for example, gyroscopic devices or moving laser systems may be used as an alternative to the more usual laser equipment.

3 EXCAVATION AND SPOIL REMOVAL IN PIPEJACKING

Several different excavation techniques are used in pipejacking. 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.

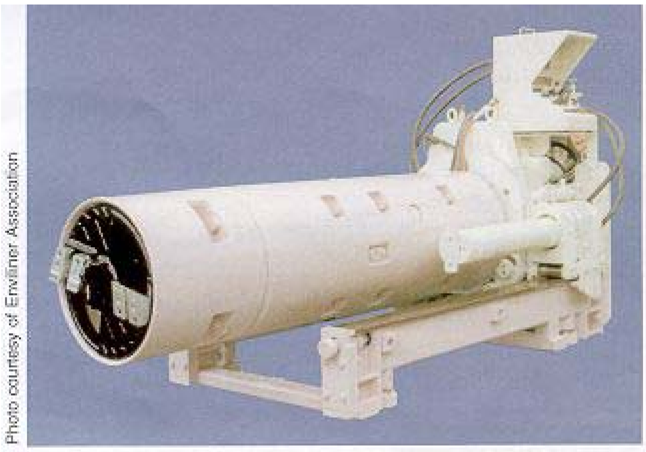
For the excavation of the ground within the pipejack, the first technique is basic hand excavation using an open shield, whereby a miner utilises hand tools, whether powered or not, to remove the ground ahead of the shield. In more difficult ground conditions it is possible to use a backacter, cutter 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.

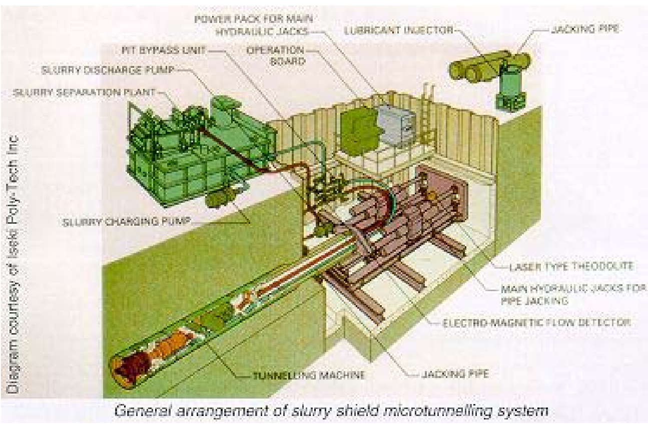
4 EXCAVATION AND SPOIL REMOVAL IN MICROTUNNELLING

Two predominant systems of spoil removal are employed at the smaller diameters associated with microtunnelling. In 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 broken ground. The auger chain is established in 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 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 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 Spoil Handling and Lubrication section). 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.

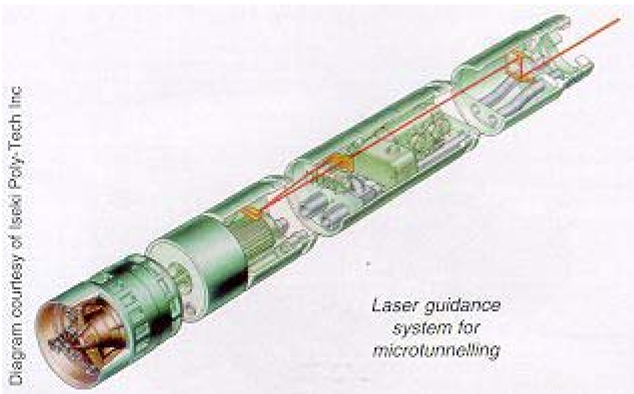


General arrangement of slurry shield microtunnelling system

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.

Microtunnelling machines with various cutting head designs

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 use successfully, but its application is restricted compared with the two main system types due mainly to limitations on the ground types in which it can operate.



Laser guidance system for microtunnelling

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 excavation method which can be compared with that used by the majority of directional drilling machines (see below).

Photo courtesy of Herrenknecht GmbH

Microtunnelling system with containerised power-plant and ancillaries

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.

5 EXCAVATION AND SPOIL REMOVAL IN PILOT AUGER MICROTUNNELLING

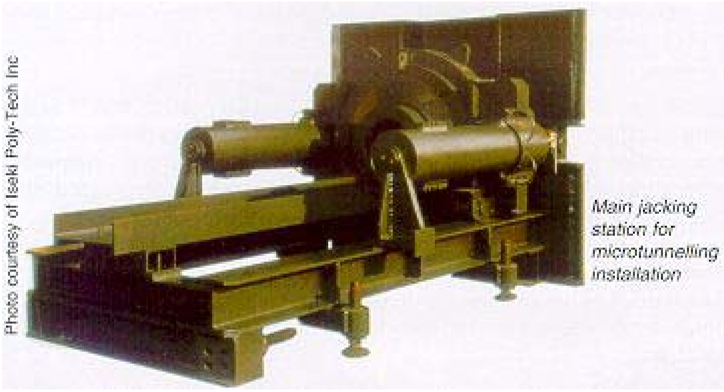
As previously mentioned the Pilot Auger Microtunnelling system is a type of hybrid between HDD and standard microtunnelling. Initially the jacking frame is established in the shaft bottom with the drill string aligned closely to the required line and level of the finished pipeline. The cutter head on 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. 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 run is completed the system normally uses an auger spoil removal technique, and normally requires a reaming phase prior to pipe installation to expand the bore diameter to 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 as a multi-pass installation with the auger being used to expand the pilot bore diameter to that required for the pipe installation. 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 start to be installed.

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.

6 JACKING FRAMES

Pipe jacking, microtunnelling and pilot auger systems are more often than not supplied with jacking frames as part of the purchase package. Frames are designed to provide the level of jacking pressure 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 and the type of shield being used.



Main jacking station for microtunnelling installation

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 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 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.

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, but it is worth repeating here that, unless ground investigation is carried out properly and a thorough knowledge of the conditions likely to be encounters along a pipejack or microtunnel route are 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 been due more to unexpected ground conditions than to any other reason.

Such failures sometimes lead to expensive recovery operations, failure of pipes already jacked into the ground or ultimately loss of some very expensive equipment.

Cutting head designed for small-bore microtunnelling in rock

9 PLANNING

In the early years of development of microtunnelling, and sometimes 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 took no account of the option to 'short cut' pipeline routes beneath obstacles that had been taken into account of or constrained the open cut option, such as having to follow roads, avoid crossing private land, and be in areas large enough to accommodate excavation equipment.

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.

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 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.

Photo courtesy of Iseki Poly-Tech Inc

Curved alignments are possible using modern equipment and techniques

As the techniques of pipejacking and, in particular, microtunnelling are 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 compete 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.

10 PIPES

Given that these techniques require the jacking of a pipe into the ground using often 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.

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 reinforce 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 or clayware, manufactured for pipe jacking to strict standards (see separate Standards section).

Photo courtesy of Naylor Clayware Ltd

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.

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 microtunnelling machine in reception chamber

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.

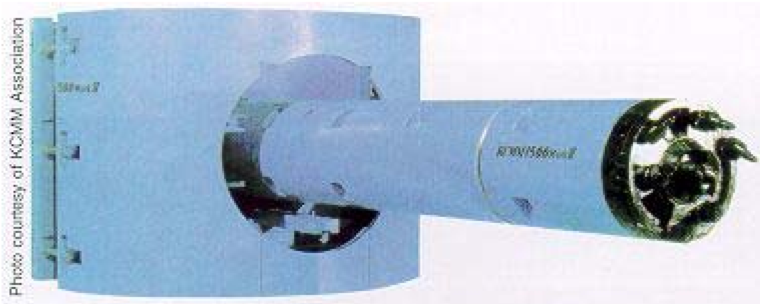
Drive shaft requirements vary greatly depending on the machine being used, ground conditions, pipe length and material, length of drive and the type of installation. They may be round, rectangular or oval; sheet piled, segmentally lined, caisson constructed, or even unsupported if ground conditions are 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 shaft-sinking rig.

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 recent 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 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.

Specialised system for shaft excavation, using a hydraulic 'clam-shell' bucket

Certain microtunnelling systems are 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 SUMMARY

a. Pipe jacking and micro tunnelling 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.