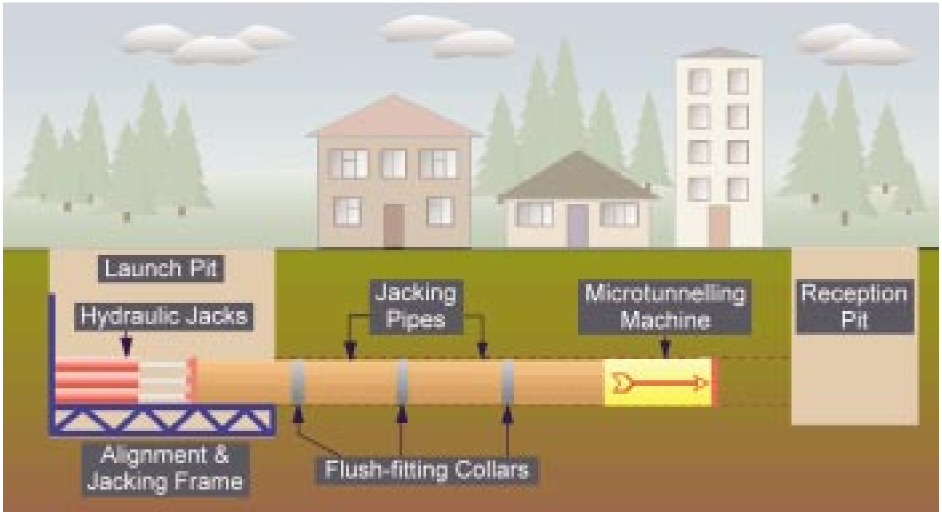
PIPEJACKING & MICROTUNNELLING

OVERVIEW

Pipejacking and microtunnelling are essentially from the same family of pipeline installation techniques, used for installations from about 150 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.

Systems are available for the installation of both main pipelines and branch connections.



Installing Pipes by Microtunnelling

APPLICATIONS

Modern technology has, in recent years, enabled both 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.

Both pipejacking and microtunnelling 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 are the line and level critical but the depth is such that both techniques tend to become more cost-effective when compared with open-cut installation.

Most microtunnelling drives are straight between shafts, although specialised systems are available for curved drives. 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 may be used as an alternative to the more usual laser equipment.

EXCAVATION AND SPOIL REMOVAL IN PIPEJACKING

Several different excavation techniques are used in pipe jacking. The first requirement for either a pipejack or a microtunnel is that a drive shaft should be sunk. The design of the shaft depends on the installation required, the size depending particularly on the lengths of the pipes to be installed. In both 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 rail-mounted and winched to and from the face by a continuous rope system. Alternatively, there may be a conveyor-belt which loads into a hoisting system at the shaft bottom.

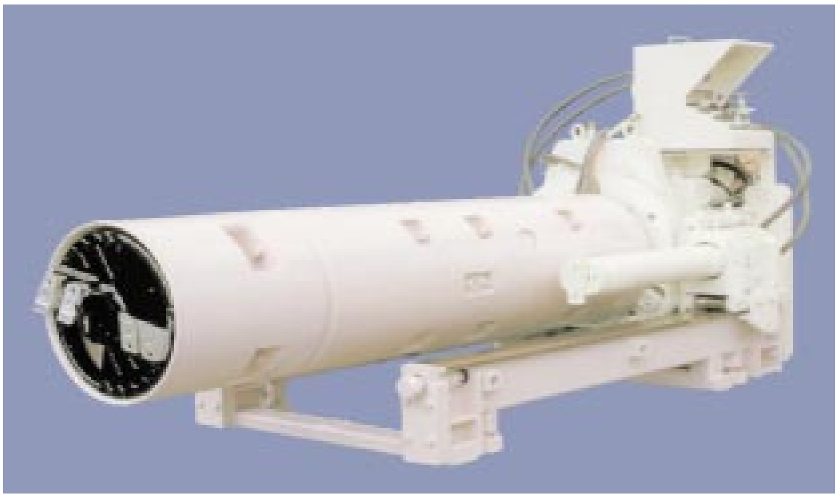
There have been instances where a vacuum system has been employed to remove spoil, whereby broken ground is sucked out of the tunnel. A `soft slurry system' has also been developed, in which a vacuum is used to discharge the slurry.

Where the ground is not self-supporting, a closed face shield is generally required. Under such conditions excavation is carried out by 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.

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 three to four metres, 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.

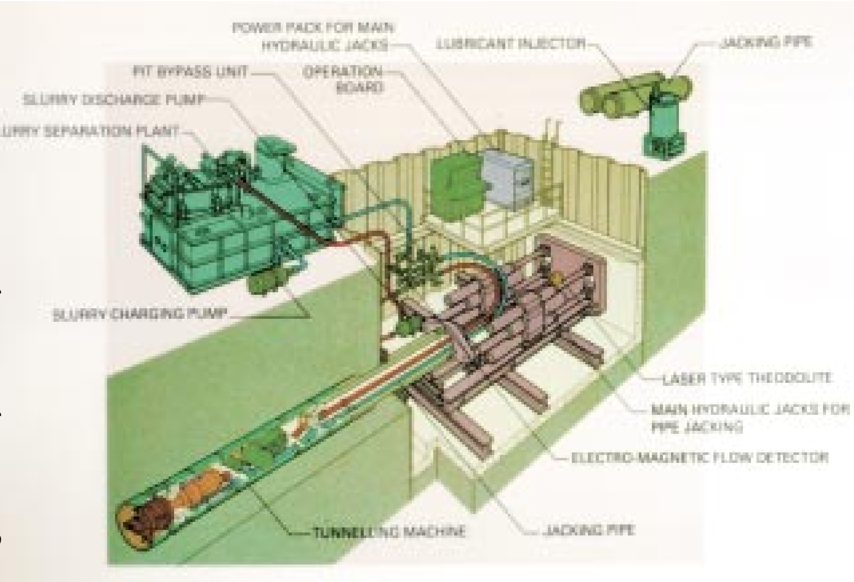
Photo courtesy of Enviliner Association



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 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.

Diagram courtesy of Iseki Poly-Tech Inc



General arrangement of slurry shield microtunnelling 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 hydrocyclones or similar apparatus. Chemical flocculents 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.

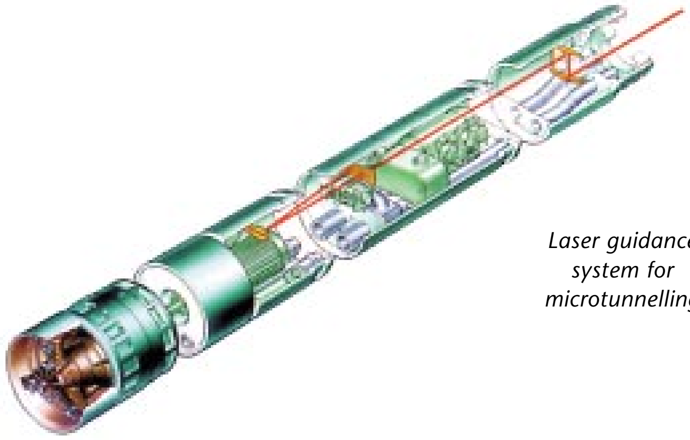
The slurry system has the advantage of being continuous, whereas auger-based methods which require the hoisting of spoil are more cyclical and involve interruptions to the operation of the cutting head.

Photo courtesy of Soltau Microtunnelling

Microtunnelling machines with various cutting head designs

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 compared with the two main system types due mainly to limitations on the ground types in which it can operate.

Diagram courtesy of Iseki Pily-Tech Inc



Laser guidance system for microtunnelling

Diagram courtesy of Iseki Pily-Tech Inc

Two other specialised microtunnelling techniques are available for small bores of less than about 200mm 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 push it aside, compacting it around the perimeter of the bore. This system is limited to compactable soil types. The second employs and excavation method which can be compared with that used by the majority of directional drilling machines. The cutter 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 system normally uses an auger spoil removal technique, and requires either a reaming phase prior to pipe installation, or an expander in front of the lead pipe during pipejacking. The system is often used as a two pass installation with the pipe starting to be installed only after the initial pilot bore has been completed.

Photo courtesy of herrenknecht CmbH

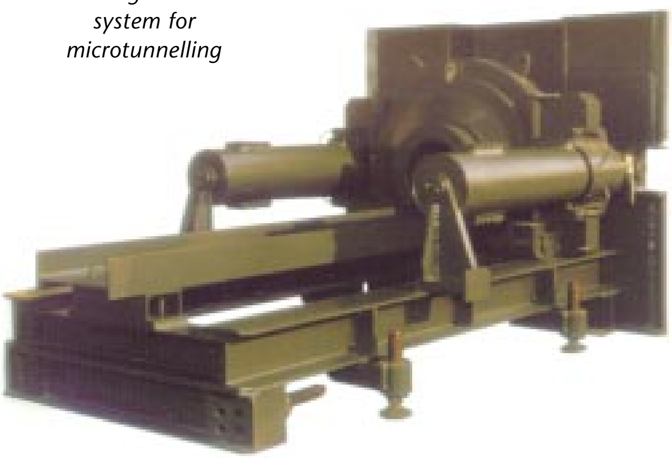
Microtunnelling system with containerised power-plant ancillaries

To complete a drive using either pipejacking or microtunnelling, a reception shaft is needed. The dimensions of this shaft should be such that the pipejacking or microtunnelling shield 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.

JACKING FRAMES

Pipe jacking and microtunnelling systems are often supplied with jacking frames as part of the purchased 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 and the type of shield.

Laser guidance system for microtunnelling



Main jacking station for microtunnelling installation

Photo courtesy of Iseki Poly-Tech Inc

GROUND CONDITIONS

The most critical factor in any pipejacking or microtunnelling project is the geology. The subject of site investigation is covered in the Surveying and Site Investigations 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 encountered 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.

Cutting head designed for small-bore microtunnelling in rock

Photo courtesy of Soltau Microtunnelling

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PLANNING

In the early years of development of microtunnelling, 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 was inefficient as it took no account of the option to `short cut' pipeline routes which had been constrained by access criteria for open cut operations, such as having to follow roads, avoid crossing private land, and be in areas large enough to accommodate excavation equipment.

Most pipejacks and microtunnels are now 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 now insist on the replacement of excavated soils with higher quality backfill. This results in the need to transport and dump excavated material, and to quarry the 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.

Photo courtesy of Iseki Poly-Tech Inc

Curved alignments are possible using modern equipment and techniques

Pipejacking & Microtunnelling

At present there are few national or international pipejacking or microtunnelling standards for engineers to work with during planning and installation. In many cases client specifications are taken as the minimum requirements for an installation. There are however several documents which have been introduced to aid the designer. These include the Guide to Best Practice for the Installation of Pipejacks and Microtunnels, published by the Pipe Jacking Association (PJA) in the UK, based partly on research at Oxford University which was funded by several UK water companies and standards organisations. The textbook Microtunnels by R Bielecki and D Stein is also used as a guide and is based largely on German experience in the field. Research is also being done in the United States through the US Corps of Engineers, which is aimed at producing an American standard for the technique. A European Union CEN committee is currently developing a standard prEn 12889 - Trenchless Construction and Testing of Drains and Sewers.

As the techniques of pipejacking and, in particular, microtunnelling are relatively new to many parts of the world, the potential for standardisation is 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.

PIPES

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 include reinforced and unreinforced 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.

In the majority of cases the pipe material is either concrete or clayware, manufactured for pipe jacking to strict standards. A typical standard for concrete is BS 5911 part 120 (1989) although at present this does not apply to microtunnelling pipes of less than 900 mm diameter. The European standard for clayware pipes is EN 295 part 7 (1996) - The requirements for vitrified clay pipes and joints for pipe jacking. The standard for reinforced concrete pipes in Japan - JSWAS (Japan Sewerage Works Association Standard) - can be applied to microtunnelling pipes for sewerage from 250 to 800 mm diameter.

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 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 standards given above, 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 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.

Pipe length varies according to the microtunnelling system used, the pipe diameter and constraints of space. Typical lengths usually range from 1.0 to 2.0 metres, although lengths of 0.75 metres are available for small diameters. 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.

LUBRICATION

The two greatest forces which 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. Friction increases with pipe diameter, as a greater surface area of pipe is presented to the internal surface of the bore.

Photo courtesy of Iseki Poly-Tech Inc

Slurry separation plant

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. 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 to assist in providing ground support throughout the duration of the pipejack.

The lubricant is conveyed by pipes installed within the main pipe string, and is injected through ports drilled through the pipe wall. Each injection port is fed by a 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.

On many projects the use of the correct lubrication materials and techniques can bring about a considerable reduction in jacking loads and ground support problems. It may also allow the use of a smaller jacking frame, thus minimising the size of the drive shaft and helping to reduce the overall cost of the project. Using modern lubricants and installation techniques, it may be possible to install up to 1000 metres of pipeline in a single drive.

Photo courtesy of Iseki Poly-Tech Inc

Arrival of microtunnelling machine in reception chamber

INTERJACKS

Where the lubrication of a pipe may not be sufficient in itself to allow successful completion of the jacking operation (for example, where 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), another option should be considered before reducing the planned length of a pipejack. This option is the `interjack' station.

The interjack station is a ring of hydraulic jacks within a steel framework which is inserted into the pipe string at strategic points. The interjack divides the pipe string into more manageable lengths. Each length, whether between jacking frame and interjack, interjack and interjack, or interjack and shield machine, 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.

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.

The normal range of methods used for shaft sinking and construction is used also for pipejacking and microtunnelling, but 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. Requirements for shafts which are needed only for reception duties were mentioned earlier.

PhotPhoto courtesy of KCMM Association

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. One such system is equipped with a cutter head and cone crusher which moves with an eccentric radial motion and can operate in a wide range of ground conditions including soil with boulders up to 30% of the machine's outside diameter.

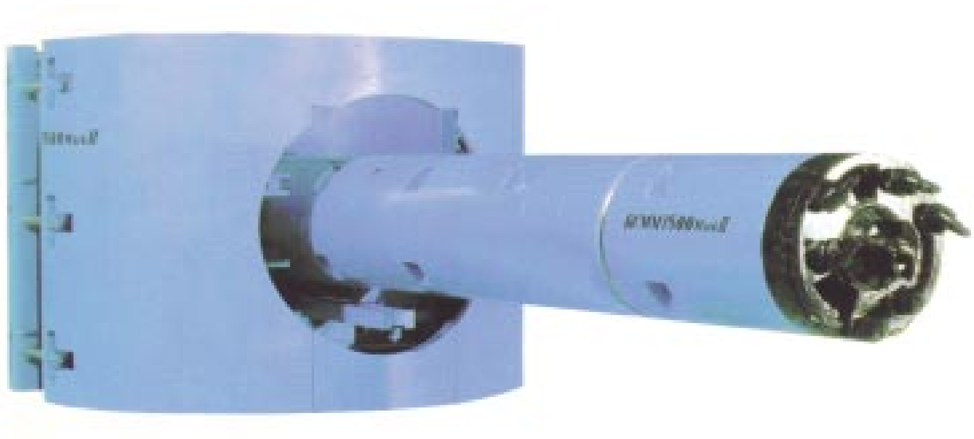

Photo courtesy of KCMM Association

Auger microtunnelling machine designed to operate from small-diameter shafts

SUMMARY

- Pipejacking and microtunnelling can be cost-effective methods of installing new pressure or gravity pipelines through most soil types and at virtually any depth.
- Precise control of gradient and alignment is possible, and the techniques are particularly suitable for medium to large diameter gravity sewers.
- 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.
- 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.