An introduction to pipe jacking and microtunelling design

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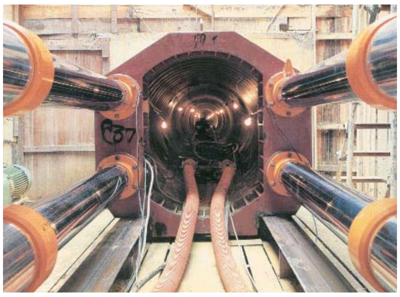
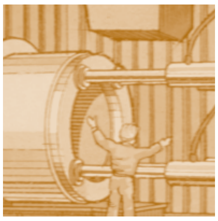
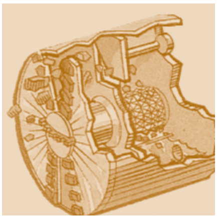
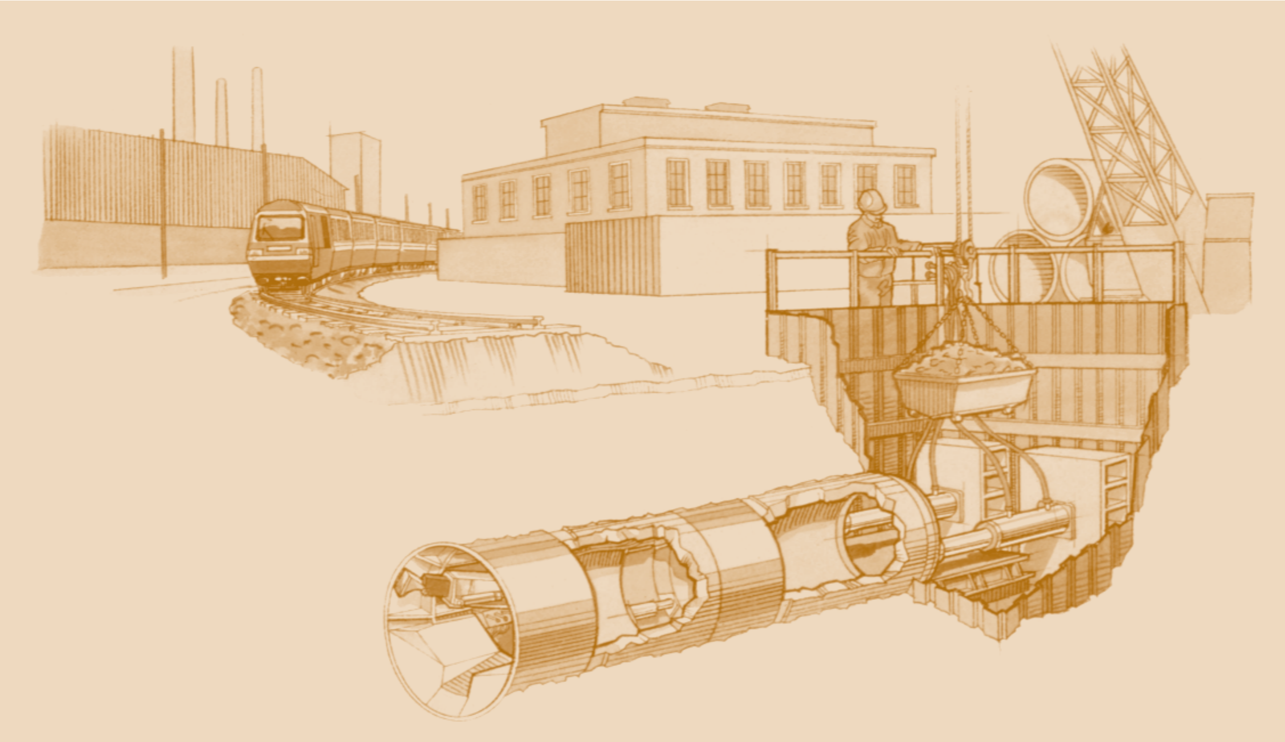
Contents







1. The pipe jacking technique



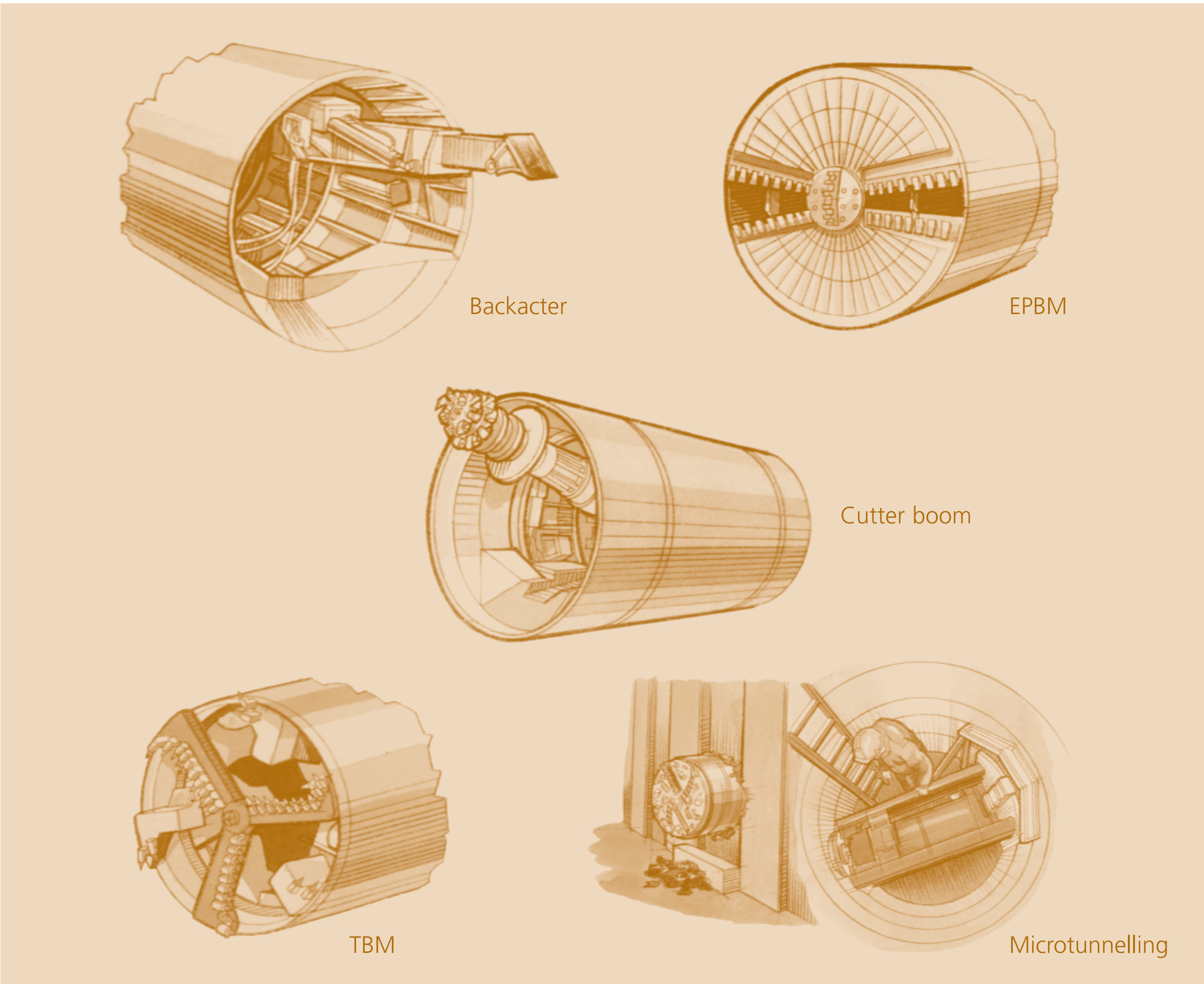
Typical pipe jacking arrangement

Pipe jacking, generally referred to in the smaller diameters as microtunnelling, is a technique for installing underground pipelines, ducts and culverts. Powerful hydraulic jacks are used to push specially designed pipes through the ground behind a shield at the same time as excavation is taking place within the shield. The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated.

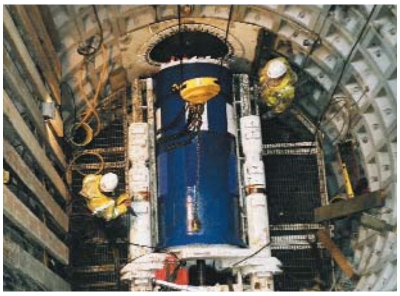
The pipe jacking technique and its components have been subject to extensive and ongoing research at leading UK universities including both Oxford and Cambridge. This has included model and full scale testing of pipes and joints and the effects of lubrication and soil conditioning on the pipe jacking process. This activity has been undertaken under the auspices of the Pipe Jacking Association with funding and participation provided through government research bodies to include the Engineering and Physical Sciences Research Council and the Construction Information and Research Association, water companies and the tunnelling and pipe jacking industry.

There is no theoretical limit to the length of individual pipe jacks although practical engineering considerations and economics may impose restrictions. Drives of several hundred metres either in a straight line or to a radius or a series of radii are readily achievable. A number of excavation systems are available including manual, mechanical and remote control. Pipes in the range 150mm to 3000mm, can be installed by employing the appropriate system. Construction tolerances are comparable with other tunnelling methods, and the pipe jacking method generally requires less overbreak than segmental tunnels and provides ground support and reduces potential ground movement.

Mechanical excavation methods are similar to those employed in other forms of tunnelling. Shields, excavation and face support can be provided for a wide variety of ground conditions.



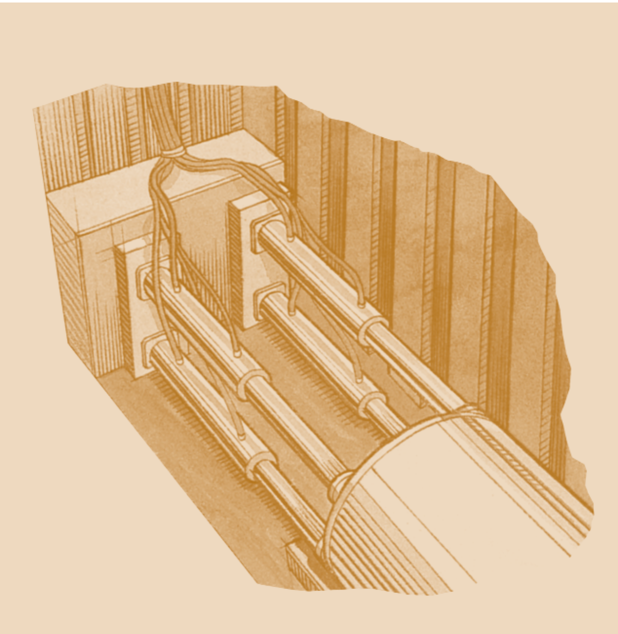
Excavation systems



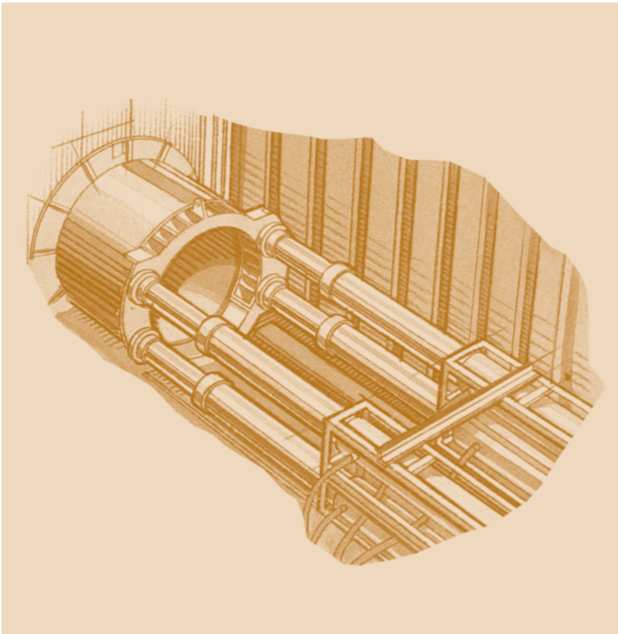
In order to install a pipeline using this technique, thrust and reception pits are constructed, usually at manhole positions. The dimensions and construction of a thrust pit vary according to the specific requirements of any drive with economics being a key factor. Pit sizes will vary according to the excavation methods employed, although these can be reduced if required by special circumstances.

A thrust wall is constructed to provide a reaction against which to jack. In poor ground, piling or other special arrangements may have to be employed to increase the reaction capability of the thrust wall. Where there is insufficient depth to construct a normal thrust wall, for example through embankments, the jacking reaction has to be resisted by means of a structural framework having adequate restraint provided by means of piles, ground anchors or other such methods for transferring horizontal loads.

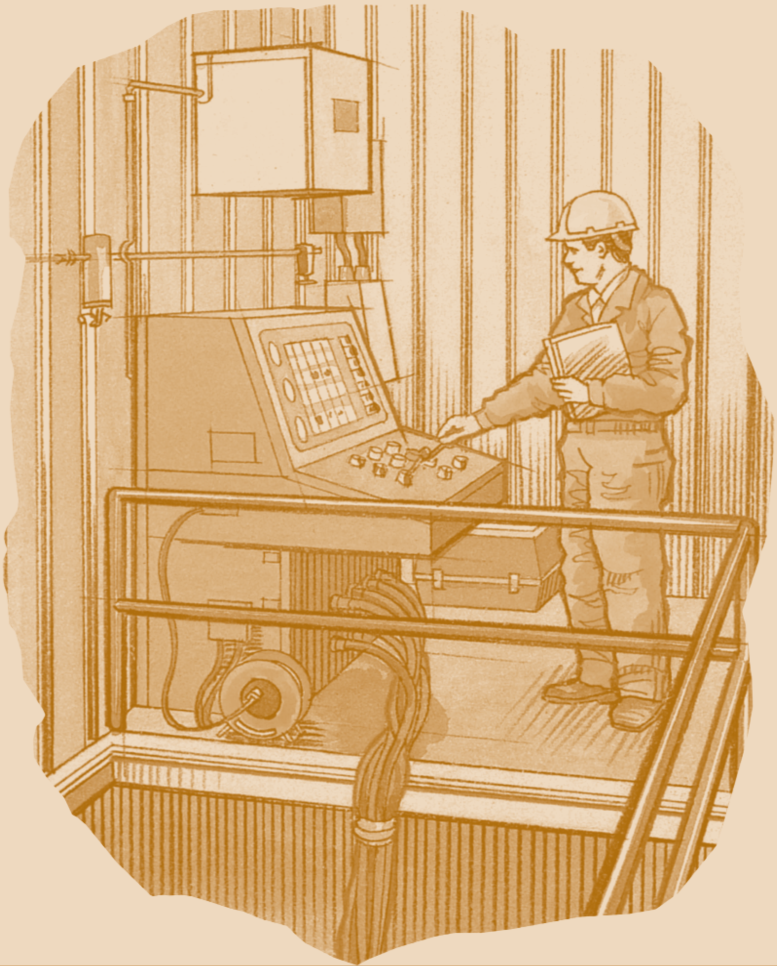
To ensure that the jacking forces are distributed around the circumference of a pipe being jacked, a thrust ring is used to transfer the loads. The jacks are interconnected hydraulically to ensure that the thrust from each is the same. The number of jacks used may vary because of the pipe size, the strength of the jacking pipes, the length to be installed and the anticipated frictional resistance.



Thrust pit set-up



Jacks and thrust ring

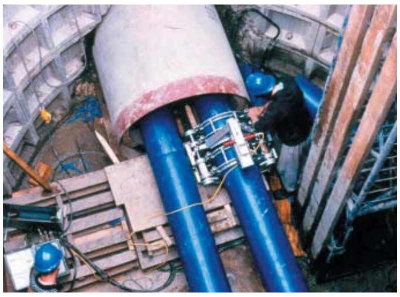


Computer guidance system for microtunnelling

A reception pit of sufficient size for removal of the jacking shield is normally required at the completed end of each drive. The initial alignment of the pipe jack is obtained by accurately positioning guide rails within the thrust pit on which the pipes are laid. To maintain accuracy of alignment during pipe jacking, it is necessary to use a steerable shield, which must be frequently checked for line and level from a fixed reference. For short or simple pipe jacks, these checks can be carried out using traditional surveying equipment. Rapid excavation and remote control techniques require sophisticated electronic guidance systems using a combination of lasers and screen based computer techniques.

When the pipejack or microtunnel is carried out below the water table it is usual to incorporate a headwall and seal assembly within each thrust and reception pit. The use of these items prevents ingress of ground water and associated ground loss, and retains annular lubricant.

2. Applications and benefits



The major applications for pipe jacking and microtunnelling include new sewerage and drainage construction, sewer replacement and lining, gas and water mains, oil pipelines, electricity and telecommunications' cable installation, and culverts. Special applications include the installation of rectangular or circular sections for pedestrian subways, road underpasses and bridge abutments.

The technique can be used to negotiate obstacles such as motorways, railways, rivers, canals, buildings and airfields in the path of pipe laying projects; to minimise the surface disruption frequently associated with open cut pipe laying methods in urban areas; or simply to provide a permanent underground tunnel construction.

Pipe jacking is primarily used as an alternative to open cut excavations or other tunnelling methods. Significant lengths are attainable at larger diameters using mechanised techniques. Reference should be made to Tables 4c and 4d for specific recommendations.

Construction methods are available to cope with both cohesive and non-cohesive soils in dry or water bearing conditions. Excavation techniques are also available for jacking through rock or mixed ground conditions, including cobbles and boulders.

Technical Benefits

Technical benefits associated with pipe jacking are:

- Inherent strength of lining
- Smooth internal finish giving good flow characteristics
- No requirement for secondary lining
- Considerably less joints than a segmental tunnel
- Prevention of ground water ingress by use of pipes with sealed flexible joints
- Provision of invert channels in larger pipes to contain the dry weather flow of a sewer in a combined system
- Less risk of settlement
- Minimal surface disruption
- Minimal reinstatement
- Reduced requirement for utilities diversions in urban areas

Safety Benefits

Pipe jacking is an inherently safer method of working than open trench construction or traditional segmental tunnelling. When considering the risks associated with deep, large section, open excavations, Health and Safety Executive guidance suggests these risks should be reduced "if appropriate using 'trenchless' technology to avoid the need to excavate the trench in the first place". Given gang size differences between the techniques and the resulting reduction in man-hours, opportunities for accidents to occur are less with pipe jacking. There is also significant reduction in the risk of injury as a result of utility strikes and interface with the public.

Environmental Benefits

There are substantial environmental benefits to be gained by the use of pipe jacking techniques when compared with the traditional open trench approach. Typically the 'trenchless' method will reduce the quantities of incoming and outgoing materials, with a consequent reduction in tipping of spoil and quarrying of imported stone fill. This in turn leads to reduced vehicle movements and subsequently less associated disruption.

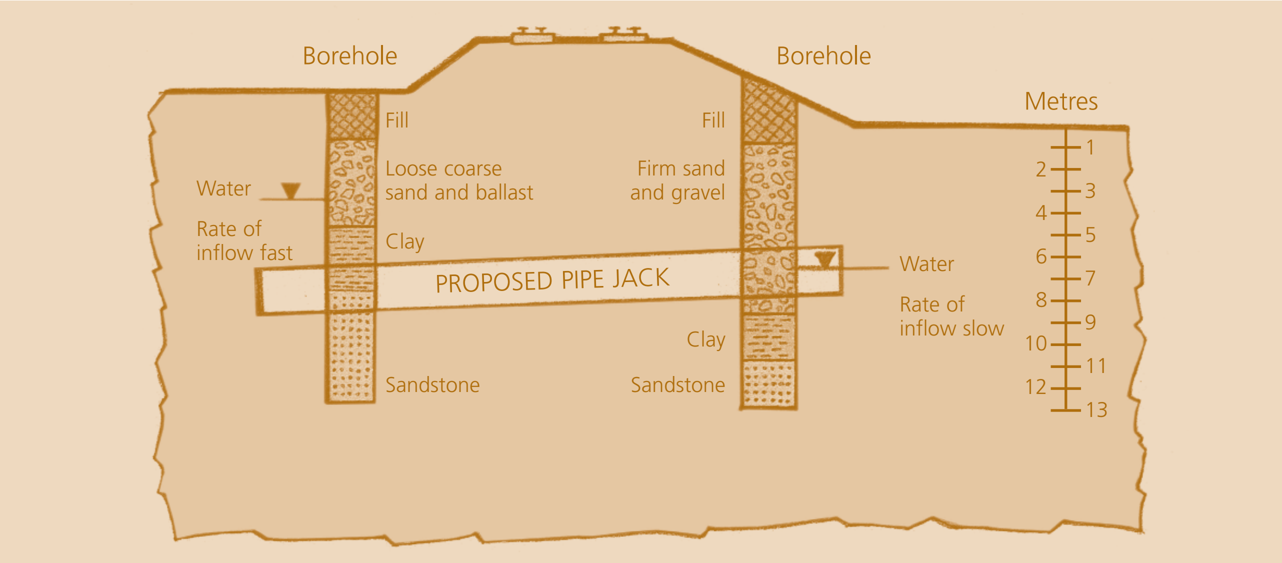
The table below compares the environmental aspects of open trench and pipe jacked sewer construction at two typical sewer diameters. The comparison assumes that excavated spoil is removed from site to a licensed tip, and that any resultant void after the pipe has been installed is replaced by imported stone backfill overlain by a coated stone surface reinstatement. Since manholes and the delivery of pipeline materials are common to both construction methods, their environmental effects can be ignored.

In many cases use of pipe jacking techniques instead of open trenching will contribute positively towards workplace safety, the interface with the general public, and the local and wider environment.

2a) Comparing the environmental aspects of open trench and pipe jacked sewer construction at two typical sewer diameters

	600mm ID pipeline 4m deep, 100m length		1200mm ID pipeline 4m deep, 100m length	
Aspect	Open trench	Trenchless	Open trench	Trenchless
Excavated width	1400mm (trench width)	760mm (OD of jacking pipe)	2350mm (trench width)	1450mm (OD of jacking pipe)
Reinstatement width	1700mm	None	2650mm	None
Excavated volume per metre of pipeline	6.1m^3	0.5m^3	10.28m^3	1.65m^3
Imported stone fill and coated stone per metre of pipeline	11.9 tonnes	None	18.27 tonnes	None
Number of 20 tonne lorry loads per 100m pipeline (muck away and imported stone)	136	8	220	21

3. Site investigation and information required on soil conditions



3a) Typical ground information required for design and costing

SITE INVESTIGATION

General

When designing and costing works to be carried out by pipe jacking, a thorough site investigation, both factual and interpretative, and report is required in order to determine the characteristics of the soils likely to be encountered, together with details of the water table in the vicinity.

The site investigation should follow the guidance given in:

- Site Investigation in Construction Part 3: Specification for Ground Investigation.
- Chapter 3 Geotechnical Characterisation of the Tunnel Lining Guide, produced by the British Tunnelling Society and the Institution of Civil Engineers *(Thomas Telford Publishing)*, 2004.
- Closed-Face Tunnelling Machines and Ground Stability, produced by the British Tunnelling Society and the Institution of Civil Engineers *(Thomas Telford Publishing)*, 2005.
- Joint Code of Practice for Risk Management of Tunnel Works, prepared jointly by the British Tunnelling Society and the Association of British Insurers *(British Tunnelling Society)*, 2003

The site investigation should be directed by a suitably qualified geotechnical specialist or geotechnical advisor with considerable experience of tunnelling schemes, under the general direction of the tunnel designer.

Desk Study

For all schemes a desk study should be carried out, assessing the available literature, maps, aerial photographs, utility plans and existing site investigations. The desk study is essential to help understand the broader geological and geotechnical issues, and should be used to determine the scope of any intrusive investigations.

Field Study

The field exploratory techniques selected should be appropriate to the type of ground and the planned depth of tunnelling. Geo-physical testing, trial pitting, static cone penetration testing and percussive or rotary-drilled boreholes may be used where appropriate. The laboratory testing programme should include tests relevant to the ground conditions and the tunnelling techniques likely to be employed. Table 3b suggests parameters to be considered in relation to each soil type.

Borehole Positions

Under no circumstances should boreholes be sunk on the line of the tunnel.

Exploratory hole positions should be chosen to provide information on the nature of the ground that will be encountered by the tunnel.

All boreholes should be properly backfilled and sealed. Piezometers should be installed where recommended.

Boreholes should always extend to the tunnel horizon and sufficiently far below the invert level to identify changes in the strata below the tunnel that could affect the construction of the tunnel.

Boreholes should be sunk adjacent to shaft locations.

Additional boreholes should be considered to identify the location of significant changes in geology or to resolve other geotechnical uncertainties.

Information Provision

All historical and site investigation information should be provided in AGS Format* and made available to the pipe jacking contractor, to enable an accurate assessment of the techniques required to execute the work.

If the route of the tunnel is varied after the completion of the site investigation, then the need for further boreholes must be reviewed to ensure that the information provided is still relevant to the revised route. Additional information may also be required as a result of the findings from the initial investigation.

** AGS Format is the standard electronic format for the transfer of geotechnical and geoenvironmental data as recommended by the Association of Geotechnical and Geoenvironmental Specialists.*

3b) Parameters to be considered in relation to each soil type

Test	Non-Cohesive Soils	Cohesive Soils	Mixed Soils	Fill Material	Rock
Unit weight and moisture content	✔	✔	✔	✔	✔
Angle of friction	✔		✔	✔	
Particle size distribution	✔	✔	✔	✔	
Abrasivity	✔	✔	✔	✔	✔
Cohesion		✔	✔	✔	
Types and proportions of minerals	✔	✔	✔	✔	✔
Standard penetration tests	✔	✔	✔	✔	
Permeability and nature of ground water flows (seasonal/tidal changes)	✔		✔	✔	✔
Toxic/hazardous constituents in the ground/groundwater	✔	✔	✔	✔	✔
Frequency and physical properties of boulders, cobbles or flints	✔	✔	✔	✔	✔
Pump down tests	✔		✔	✔	✔
Presence of gases				✔	✔
Compressive strength					✔
Rock quality designation (RQD)					✔
Core logging (TCR, SCR, FI)					✔
Tensile strength					✔
Specific energy (excavatability)					✔
Slake durability					✔
Geological description	✔	✔	✔		✔
Plasticity indicees (SL, PL, PI)		✔	✔		

Unstable Ground Conditions

Tunnelling methods depend on the stability of the ground. Where unstable conditions are likely to be met, the face of the tunnel must be controlled to prevent ground loss, and to enable mining to take place safely.

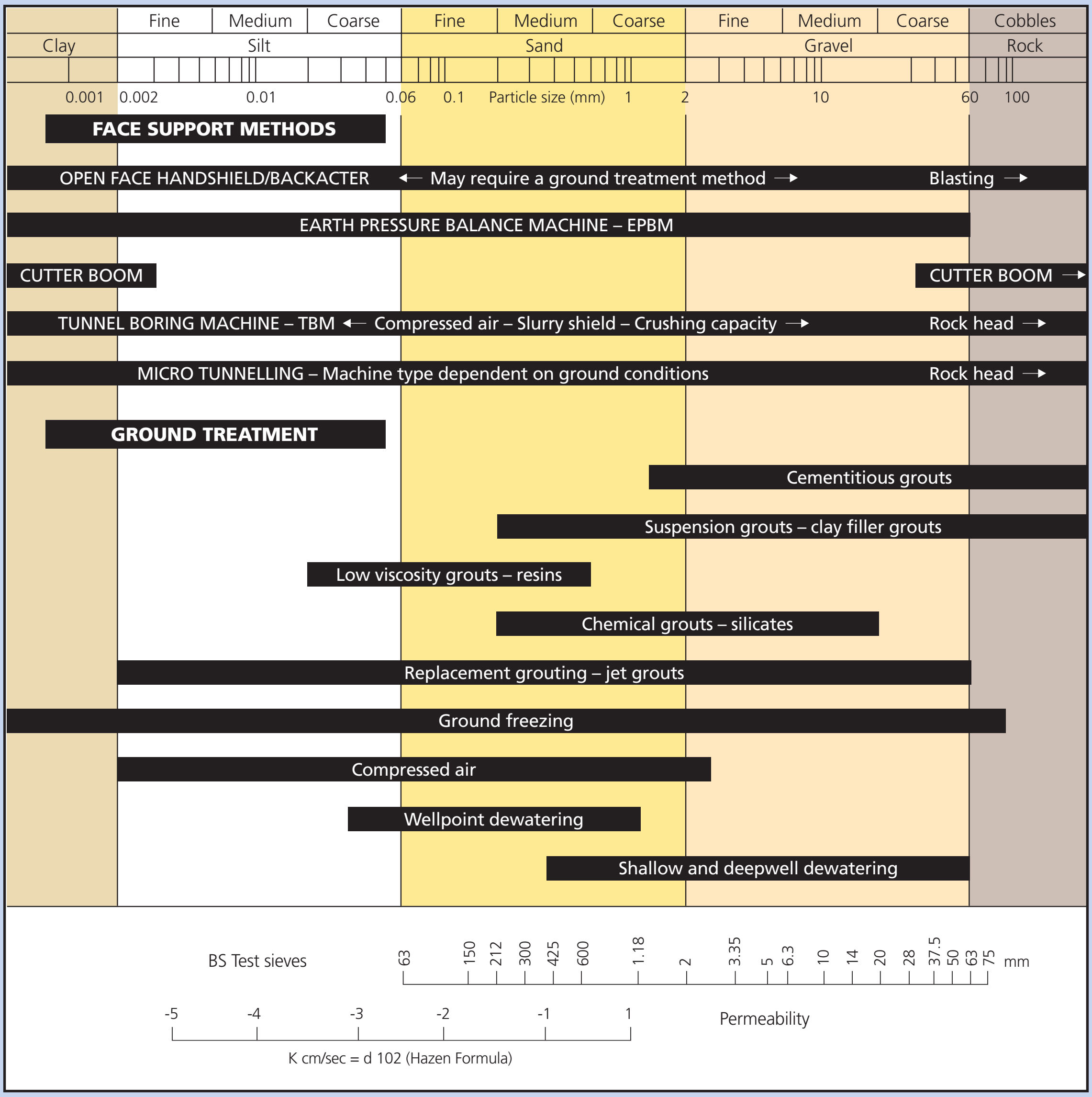
A controlled face can be achieved by using suitable tunnelling methods such as compressed air, full face earth pressure balancing machines, or slurry/soft ground TBMs.

Alternatively a stable face when pipe jacking can be achieved using the following geotechnical processes:

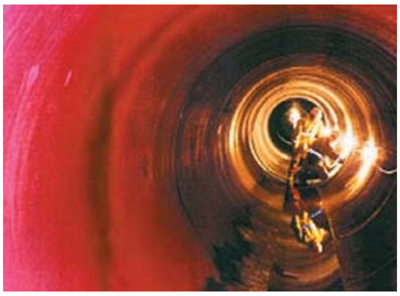
- Dewatering by well points or deep wells
- Grouting with cement, cement/bentonite, or chemicals
- In extreme cases, ground freezing

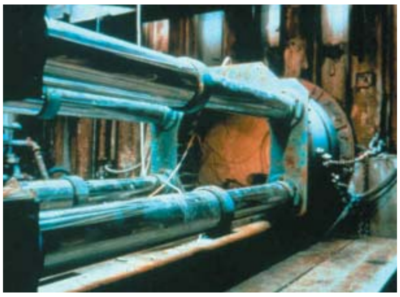
The choice of process is a function of the nature of the ground, the water content, and in particular the particle size analysis. The table below gives an indication of the process applicable to various conditions, but because of the specialist nature of such activity, detailed advice should be sought from a geotechnical engineer.

3c) Face support and ground treatment methods for varying ground conditions



4. Design and construction methods





Prior to embarking on a detailed construction design and method analysis, the client's engineer will generally have ascertained the basic design parameters to meet the requirements of the scheme.

For a sewerage system these are likely to include:

- Hydraulic requirements
- Preferred route
- Manhole requirements
- Depth
- Gradient

Following an assessment of engineering, environmental and cost parameters, pipe jack excavation method and shaft construction will also be governed by a number of factors which include:

- Ground conditions
- Details of existing services and underground structures
- Location of manholes and working areas
- Lengths required
- Diameters of pipeline
- Economics

Ground conditions will play a major role in determining the type of shaft to be constructed, the pipe jack excavation method and any ground support systems to be used. Each of these may have limitations in terms of either the diameter or length of drive. The interface between these variables, together with physical considerations, such as the location of manholes and the size of working areas, will provide an optimum solution or range of solutions which can then be appraised on the basis of cost and value engineering.

When considering the use of pipe jacking as an alternative to open cut, an assessment of the advantage of realignment should be made. This may shorten the overall length of the pipeline.

Working shafts

A range of working shaft construction methods can be used for pipe jacking operations, including:

- Segmental lining
- Pre-cast or cast insitu caissons
- Sheet piling or secant piling
- Shallow trench sheeted or timber supported excavation
- Battered excavation
- Ground anchorages

In certain instances, ground treatment or groundwater management methods may be required to enable the construction of the shaft to proceed.

These include:

- Well pointing and deep wells
- Compressed air
- Suspension grouts
- Chemical stabilisation
- Ground freezing

The tables provide a guide to the most common practice for selecting shafts, but are not exhaustive.

4a) Design of working shafts in dry ground

Dry Cohesive, Dry Non-Cohesive and Dry Mixed and Fill Conditions

TYPE	SIZE AND SHAPE	DEPTH	GROUND TREATMENT	REMARKS
Segmental	2.4m dia and above	Unlimited	Not required	Diameter dependent on pipe jacking method, rig & depth considerations
Sheet piled	Any	Generally Up to 15m	Not required	Size and shape dependent on pipe jacking method and rig
Secant piled	Any	Generally Up to 20m	Not required	Size and shape dependent on pipe jacking method and rig
Trench sheeted	Any	Up to 6m	Not required	Size and shape dependent on pipe jacking method and rig
Pre-cast caisson rings	2.4 to 4m dia	Generally Up to 15m	Not required	Suitable for microtunnelling
Cast insitu caisson	–	–	–	Not applicable
Battered excavation	Any	Shallow	Needed if angle of repose of soil exceeded	For shallow work only
Ground anchorages	Any	Surface level	Not required	Generally used for drives through embankments

4b) Design of working shafts in wet ground

Wet Cohesive, Wet Non-Cohesive and Wet Mixed and Fill Conditions

TYPE	SIZE AND SHAPE	DEPTH	GROUND TREATMENT	REMARKS
Segmental	2.4m dia and above	Limited by ground treatment	Wet caisson method	Grab excavation below water, generally 50m depth
			Well pointing	Up to 7 metres depth
			Deep well dewatering Compressed air Suspension grout Chemical stabilisation Ground freezing	Depth Dependant on Ground Conditions & Water Level
Sheet piled	Any	Generally Up to 15m	Well pointing	Up to 7 metres depth
			Deep well dewatering	Depth dependent on water table draw down and pile cut-off level
Secant piled	Any	Generally Up to 20m	May be required for base stability	Needs large working area
Trench sheeted	–	–	–	Not recommended
Pre-cast caisson	2.4 to 4m dia	Generally Up to 15m	May be required for base stability	Suitable for microtunnelling
Cast insitu caisson	Any	Up to 40m	May be required for base stability	Generally for major project
Battered excavation	–	–	–	Not applicable
Ground anchorages	Any	Surface level	Ground treatment and/or piling may be required to provide jacking reaction	Generally used for drives through embankments

Notes

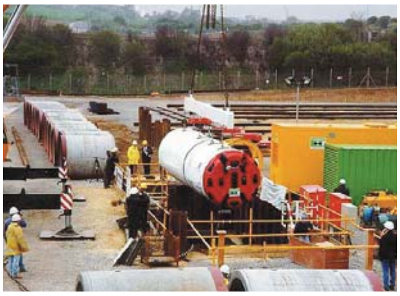
(a) Working shafts can be converted to permanent works, ie segmental or caissons to manholes or piled shafts to manhole rings.

(b) The type of construction is not generally governed by the ground treatment method, which should be considered as an assistance to the construction method.

(c) In rock, the shaft design will depend on the characteristics of the material.

(d) Most shaft construction methods require external concrete collars. Consideration should be given during design to the overall plan area and depth.

(e) For very deep drives in water bearing ground, consideration should be given to pressure limitations of available equipment.



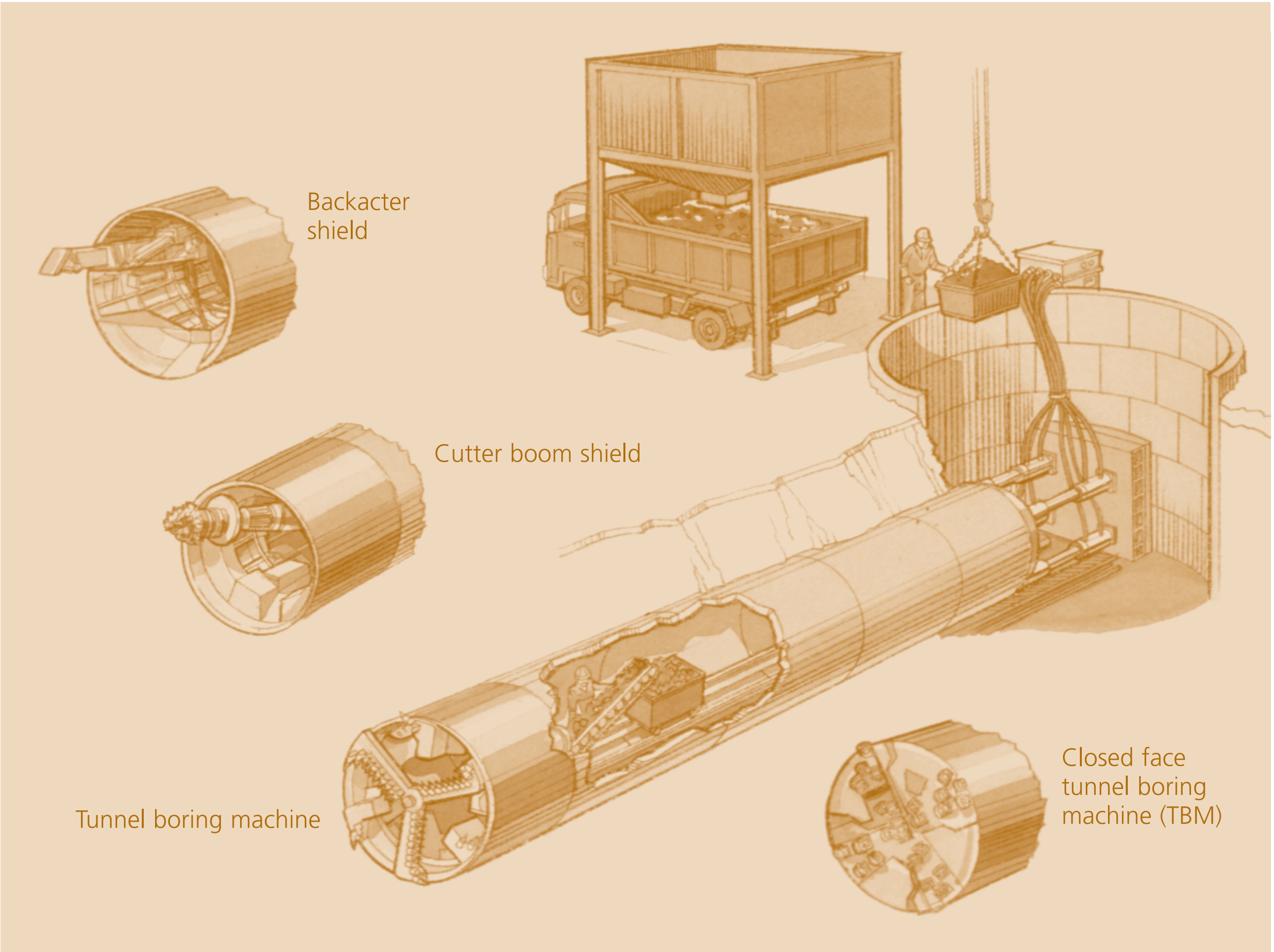
Pipe jacking excavation methods

A range of pipe jacking excavation methods are illustrated. In most cases, the choice of method will also depend on the selection of the appropriate ground support technique:

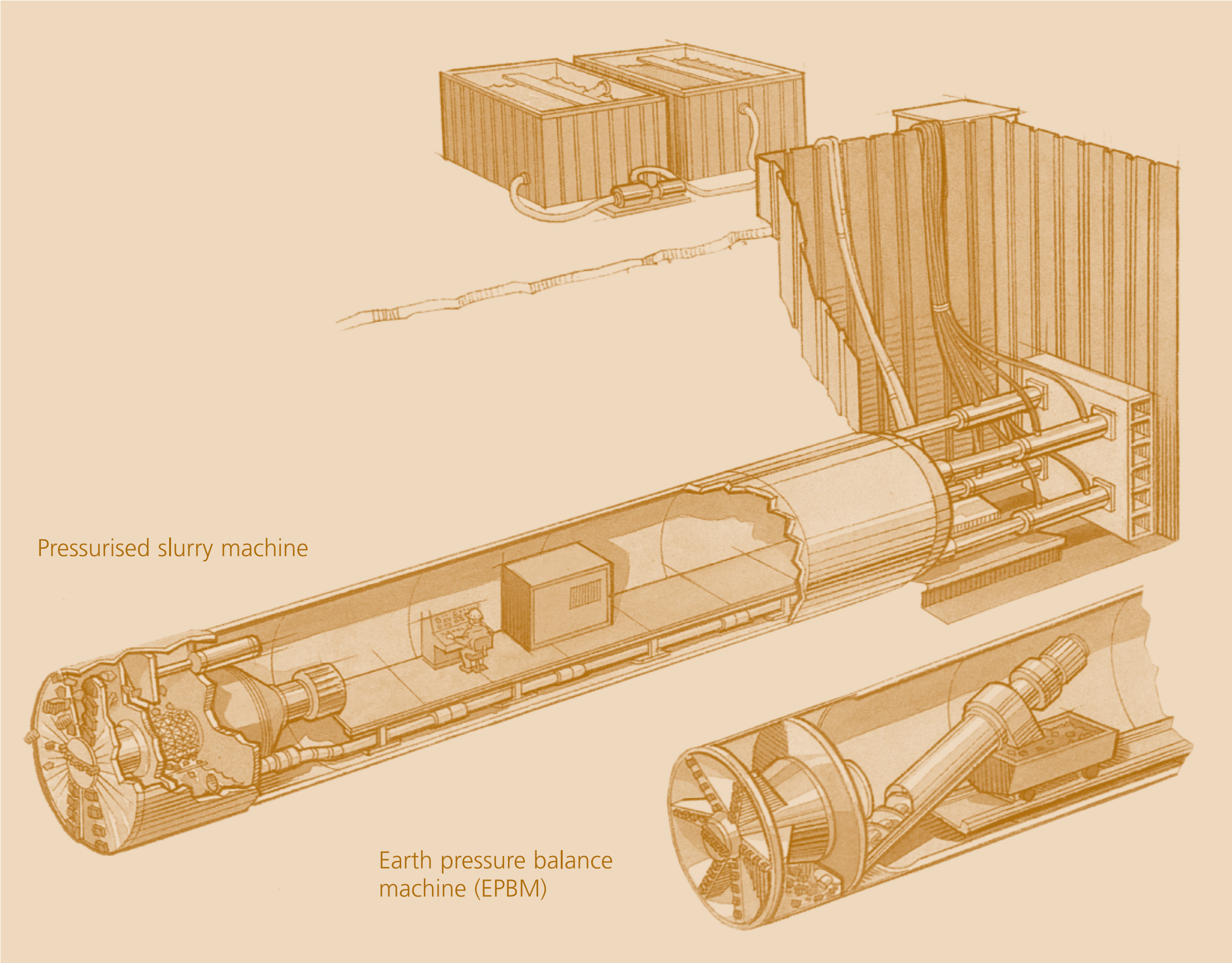
Tunnel boring machine (TBM) – a shield having a rotating cutting head. Various cutting heads are available to suit a broad range of ground conditions.

Cutter boom shield – an open face shield in which a cutter boom is mounted for excavation purposes.

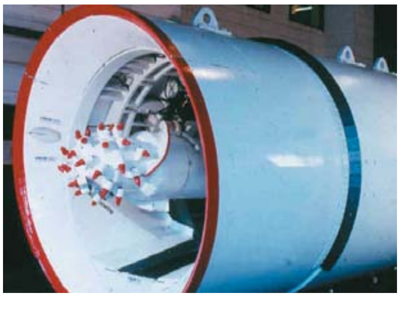
Backacter shield – an open face shield in which a mechanical backacter is mounted for excavation purposes.



Pipe jacking excavation methods



Pipe jacking excavation methods



Pressurised slurry machine – 'full-face' tunnel boring machine in which the excavated material is transported from the face suspended in a slurry. Various cutting heads are available to suit a broad range of ground conditions and may incorporate internal crushers to deal with cobbles and small boulders. The pressure of the slurry is used to balance the groundwater and face pressure.

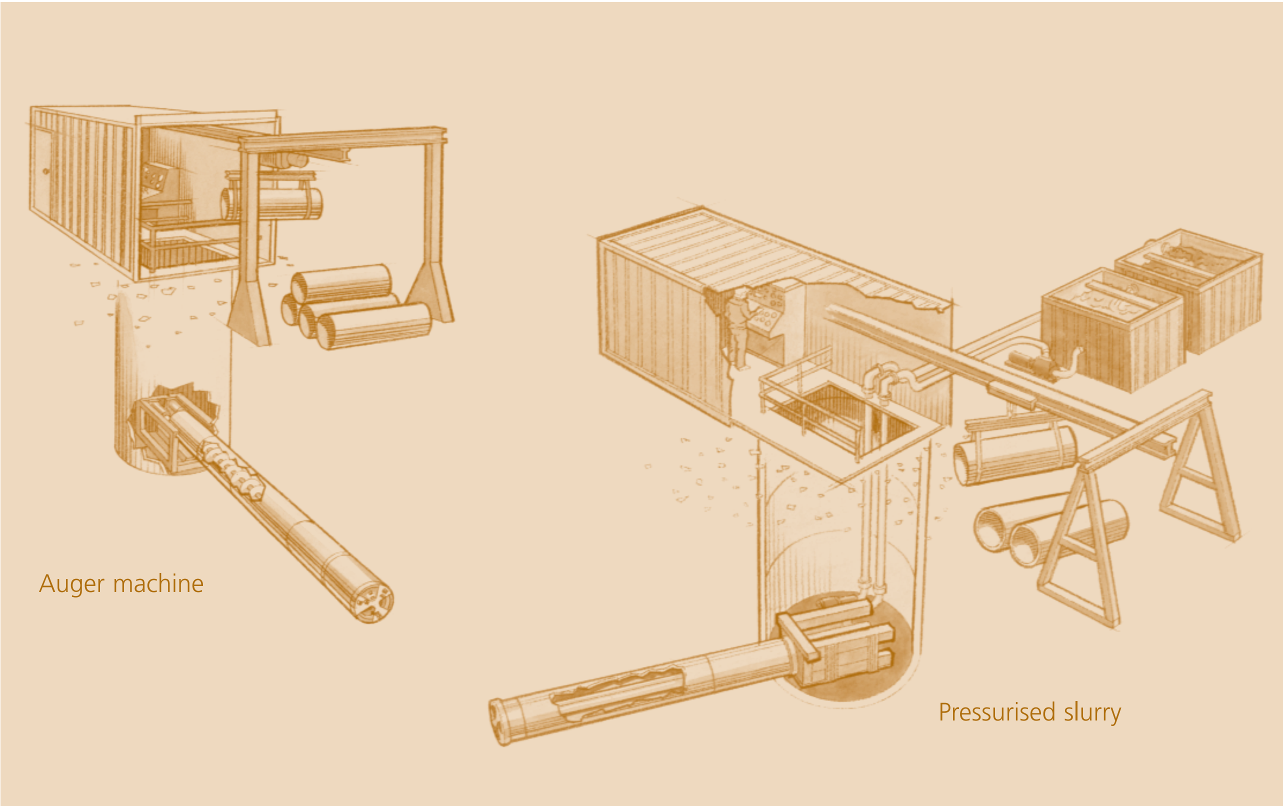
Earth pressure balance machine (EPBM) – a 'full-face' tunnel boring machine in which the excavated material is transported from the face by a balanced screw auger or screw conveyor. The face is supported by excavated material held under pressure behind the cutter head in front of the forward bulkhead. Pressure is controlled by the rate of passage of excavated material through the balanced screw auger or valves on the screw conveyor.

Microtunnelling machine – Fully guided machine remotely controlled from the surface, 1000 millimetre internal diameter and below, where man entry is not acceptable. These microtunnelling machines are generally of two types, both having face support capability:

Pressurised slurry – As with the Pressurised slurry TBM, excavated material is transported from the face to the surface suspended in a slurry.

Auger machine – Where excavated material is transported from the face to the drive pit via a cased screw auger.

Open hand shield – an open-face shield in which manual excavation takes place. For 1200mm internal diameter and above, and for very limited drive lengths on the grounds of health and safety.



Microtunnelling excavation methods

4c) Indicative drive lengths (e.g., between shafts) and maximum number of drives by internal diameter of pipeline

<table>
<tr><th>EXCAVATION TECHNIQUE</th><th><0.9M</th><th>0.9M</th><th>1.0M</th><th>1.2M</th><th>1.35M</th><th>1.5M</th><th>1.8M</th><th>>1.8M</th></tr>
<tr><td rowspan="2">Pipe jack – machine; remote operation from surface</td><td colspan="3">Drive length limited only by capacity of jacking system</td><td colspan="2" rowspan="2">250m</td><td rowspan="2">400m</td><td colspan="2" rowspan="2">>500m</td></tr>
<tr><td colspan="2">Man entry not acceptable</td><td>Avoid man entry</td></tr>
<tr><td>Pipe jack – machine; operator controlled below ground</td><td colspan="3">Not Acceptable</td><td>125m</td><td>200m</td><td>300m</td><td>500m</td><td>>500m</td></tr>
<tr><td rowspan="3">Pipe jack – hand dig</td><td colspan="3" rowspan="3">Not Acceptable</td><td>25m</td><td>50m</td><td>75m</td><td colspan="2">100m</td></tr>
<tr><td colspan="3" rowspan="2">2 drive lengths</td><td colspan="2">1 drive length</td></tr>
<tr><td colspan="2">Use minidigger if > 2.1m</td></tr>
</table>

4d) Pipe jacking excavation methods for dry and wet ground

<table>
<tr><th rowspan="2">EXCAVATION METHOD</th><th rowspan="2">PIPELINE INTERNAL DIAMETER</th><th colspan="2">DRY GROUND
(Dry cohesive, dry non-cohesive and dry mixed and fill conditions)</th><th colspan="2">WET GROUND
(Wet cohesive, wet non-cohesive and wet mixed and fill conditions)</th></tr>
<tr><th>FACE SUPPORT</th><th>REMARKS</th><th>FACE SUPPORT</th><th>REMARKS</th></tr>
<tr><td>Open face TBM</td><td rowspan="4">1200-3000</td><td rowspan="3">None</td><td>Only applicable to stable face conditions, including rock</td><td rowspan="3">Chemical stabilisation
Suspension grouts
Well points
Deep wells</td><td>Only applicable to stable face conditions</td></tr>
<tr><td>Cutter boom shield</td><td>Only applicable to strong cohesive soils and soft rock</td><td>–</td></tr>
<tr><td>Backacter shield</td><td>Only applicable to stable face conditions</td><td></td></tr>
<tr><td>Pressurised slurry machine</td><td rowspan="3">In-built method</td><td>–</td><td>In-built method</td><td>–</td></tr>
<tr><td>Earth pressure balance machine</td><td>1400-3000</td><td>–</td><td>Additives in certain ground conditions</td><td>Limited to water pressure head</td></tr>
<tr><td>Microtunnelling</td><td>150-1000</td><td>–</td><td>Dependant on type of machine</td><td></td></tr>
<tr><td>Open hand shield</td><td>1200-3000</td><td>Consider face boards and soil trays</td><td>Limited by safety considerations and exposure to HAVS (see note b)</td><td>Chemical stabilisation
Suspension grouts
Well points
Deep wells</td><td>Subject to ground conditions.
Limited by safety considerations and exposure to HAVS (see note b)</td></tr>
</table>

See notes overleaf

Notes

(a) Information in Table 4c) is extracted from *Tunnelling and pipe jacking: guidance for designers* published by the Health & Safety Executive, Pipe Jacking Association and British Tunnelling Society which is available from *www.pipejacking.org*.

(b) For further information see *Guidance on the design of hand excavated pipe jacks* available from *www.pipejacking.org.uk*.

(c) When selecting mechanical excavation methods the drive lengths may be influenced by the need for interjacks, lubrication methods and other economics.

(d) When selecting a 'full face' machine, consideration should be given to the ability of the machine to deal with cobbles, boulders, or any other obstructions.

(e) Disposal of spoil from slurry machines may require special handling and disposal facilities at working shafts.

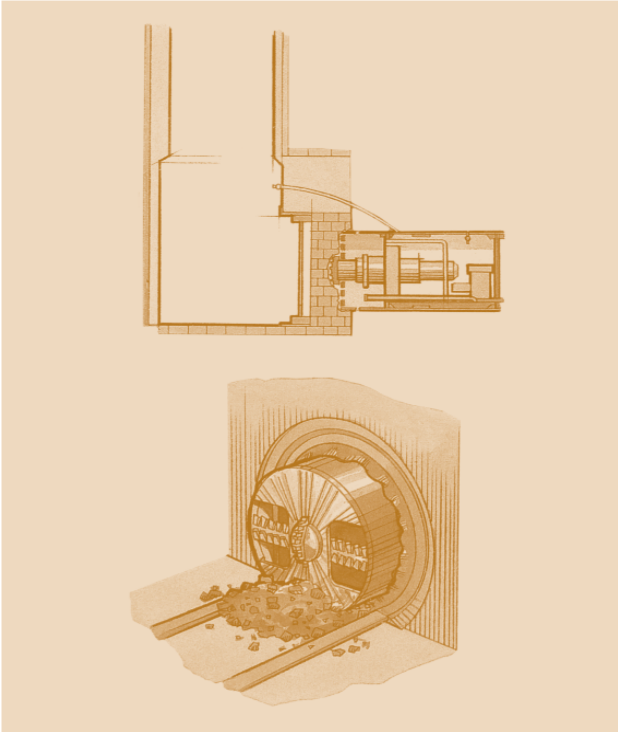
(f) Rock can be excavated using a cutter boom shield, a full face TBM, a pressurised slurry machine or a microtunnelling machine.

(g) Consideration must be given to ground stability around the pipe jack entry and exit eyes in shafts. This can be by a number of methods, for example, the use of gland assemblies, pressure grouting, or localised dewatering.

Slurry management

Where a pipejack or microtunnel is to be installed using a pressurised slurry system the design control and management of the slurry and the separation equipment that removes the excavated soils from the slurry is critical to the success of the pipejacking or microtunnelling operation.

A slurry system uses water based fluid (slurry) to transport excavated soils from the tunnelling machine to the surface where the excavated soil is removed from the slurry enabling the re-use of the slurry for further excavation.



Pipe jacking eyes

There a number of factors that guide the formulation of the slurry. The main consideration is the geology through which the pipejack or microtunnel is to be constructed but also the length and depth of the drive is important.

Contact **Pipe Jacking Association** members for further advice and assistance.

Safety

As stated in Section 2, pipe jacking is an inherently safer method of working than open trench construction or segmental tunnelling.

Safety statistics gathered by the Pipe Jacking Association for microtunnelling and pipejacking construction are many times better than the industry standard for Civil Engineering. Advances in mechanisation have significantly reduced the exposure of the workforce to hand arm vibration (HAVS) and atmospheric pollutants.

With the advent of the Construction Design and Management (CDM) Regulations clients and designers have significant responsibilities imposed on them and may find that risks may be eliminated or mitigated by opting for the pipejacking or microtunnelling method of construction.

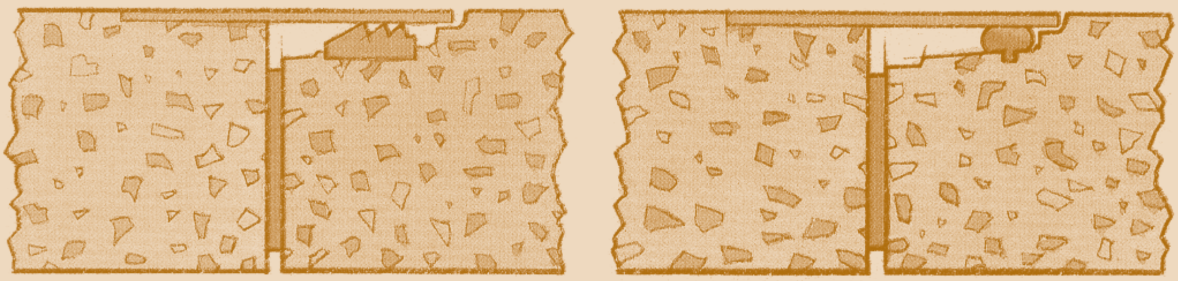
5. Pipe jacking pipes

Concrete is the most common material used as a primary lining for pipe jacking, with the largest standard range having diameters from 450mm to 3000mm or greater if required. For smaller diameters high strength vitrified clay pipes are commonly used. Sizes commonly available in clay range from 150mm diameter to 700mm diameter. However both steel and grp pipes may be used for jacking, although these are most likely to be utilised for specialist applications.

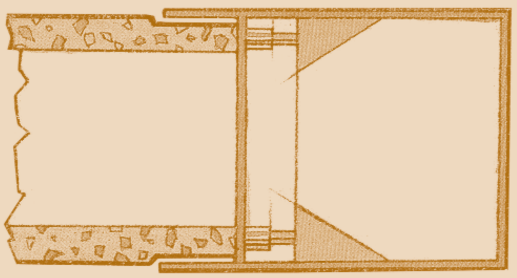
The choice of material can be influenced by diameter, length of drive, and in some cases, by ground conditions or the intended end use of the pipeline. Pipes of composite manufacture, for example concrete and grp, have been produced to meet exceptional conditions. Guidance on jointing techniques together with advice on joint packings should be obtained from the manufacturer.

The majority of pipe jacks are for sewerage, drainage and other utility applications, and such projects normally involve concrete jacking pipes in larger diameters and concrete or clay in the smaller microtunnelling sizes.

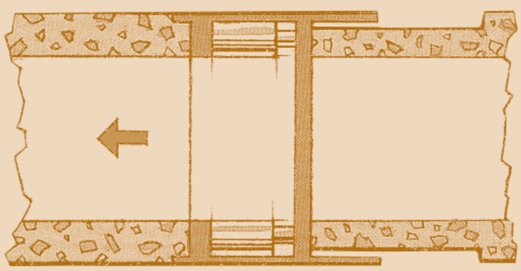
Butt joints incorporating collars



Typical flexible joints



Rebated lead pipes



Interjack pipes

Standards: Concrete pipes

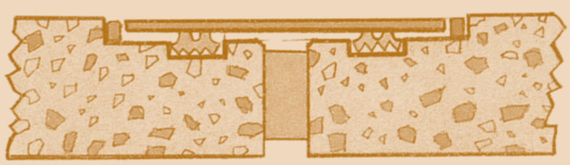
Concrete jacking pipes should be manufactured in compliance with BS EN 1916. They should be obtained from a certified manufacturer, such that they will be supplied from a factory which is quality assured to IS0 9002 and the pipes should be kitemarked.

Concrete jacking pipes produced in accordance with BS EN 1916 to achieve the loading and strength to resist jacking forces, although higher strengths can be achieved to meet more onerous superimposed loading conditions. Pipes are available in lengths between 1.2 and 2.5 metres and are designed such that the jacking forces may be transmitted along the pipeline without damage to the joint.

Flexible joints must comply with BS EN 1916 in terms of watertightness at given draw and deflection limits, but will differ in design detail from manufacturer to manufacturer. A secondary seal may be incorporated in the joint if required.

Specially rebated leading pipes can be produced for insertion into the jacking shield. Similarly, special rebated pipes are produced for the trailing pipes at intermediate jacking stations. Leading pipes at interjack stations can be supplied to fit directly to an interjack shield or may be produced with an integral interjack shield.

Packers must be incorporated into each joint in order to distribute the jacking pressure and avoid point loads and to prevent damage to the ends of the pipes during the jacking process. Medium density fibreboard (MDF) has been found to be the best material from which to fabricate joint packers. Research carried out by the Pipe Jacking Association has shown that MDF is the most flexible of the timber based materials, having excellent recovery characteristics. The packers should not extend over the full joint width, a small gap being left to the inside surface of the pipes to prevent localised spalling.



Clay pipe joint detail

Standards: Clay pipes

Vitrified Clay pipes for microtunnelling and pipe jacking are manufactured to achieve high axial strength. They will withstand the jacking forces used during installation, and the ground loads imposed during their working life. Pipes should be manufactured in accordance with BS EN295-7 and BS EN12889: 2000. They should be obtained from a certified manufacturer, such that they will be supplied from a factory which is quality assured to IS0 9002, and the pipes should be kitemarked.

The pipe ends are machined to produce an accurate joint profile. Collars are typically fabricated from Stainless Steel. The joint will incorporate a rubber seal, most likely EPDM (Ethylene Propylene Diene Monomer). Pipe lengths are usually in the 1.0-2.0 metre range for the more common smaller diameters.

As with concrete jacking pipes packers are used to prevent damage to the pipe ends during the jacking process.

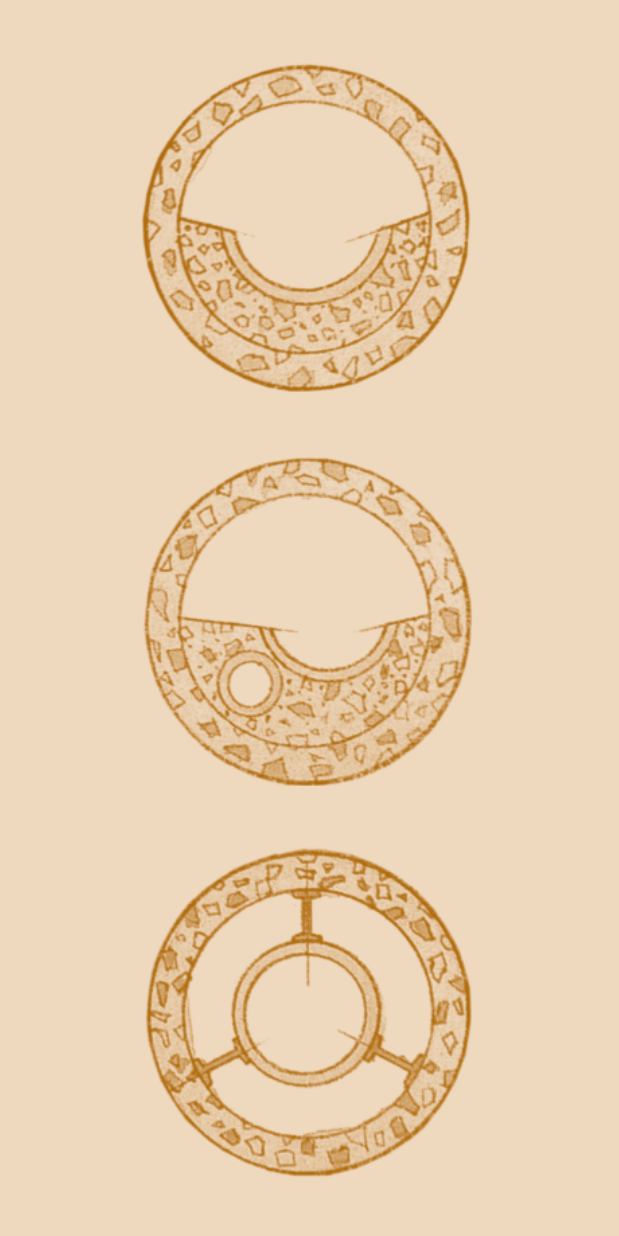
Steel pipes

Steel pipes of varying lengths are used as sleeves for the installation of gas, oil and water pipelines where fine tolerances in line and level are not usually required. Factors such as welding time and pit size should be considered when determining the length of each individual pipe.

Secondary linings and/or reinverting

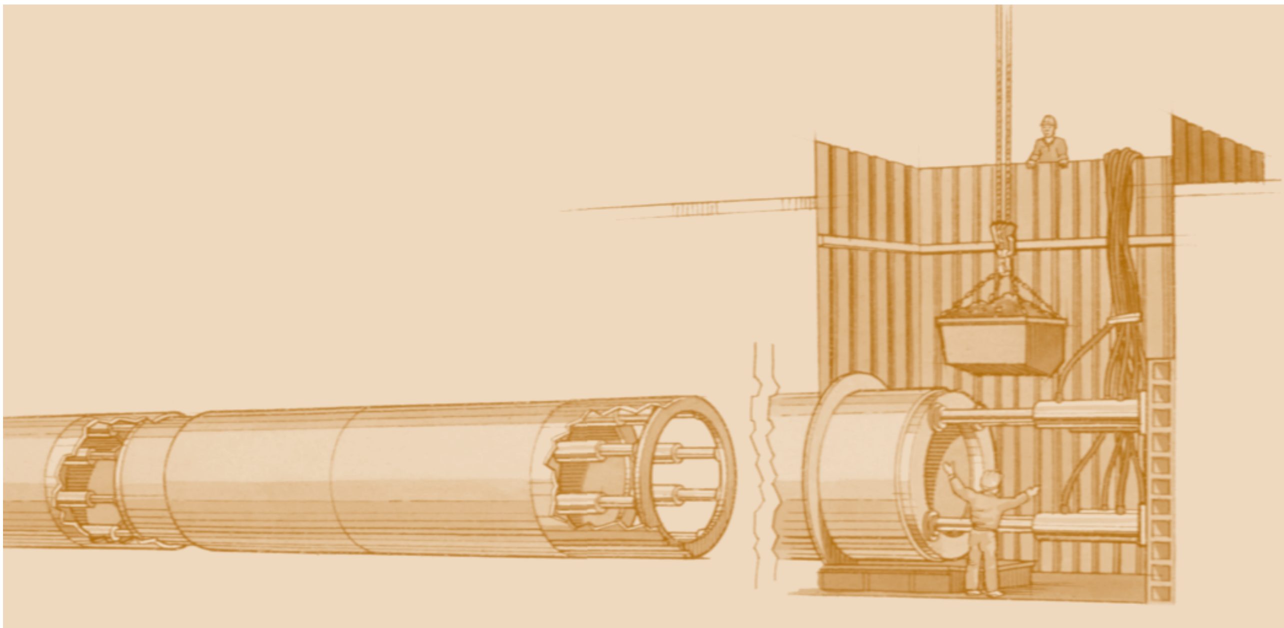
There may be certain drives where because of the nature of the ground, the required length of drive, or end use, it is considered desirable to jack a pipe of larger diameter than required as the primary lining or sleeve. The finished diameter is then achieved by either reinverting or by installing smaller diameter secondary pipes.

Secondary inverts and pipes can be constructed in a range of materials such as concrete, steel, upvc, or vitrified clay, depending on the material to be conveyed. Secondary pipe linings can be laid in the invert or supported on steel centralisers. Where required the annular space can be filled with a cementitious grout.



Typical reinverting & secondary lining detail

6. Jacking lengths, loads and tolerances



Intermediate jacking stations

Jacking lengths

Refer to tables on page 17. The length over which a pipejack can be installed is dependent upon a number of interrelated and variable factors: the stability and friction characteristics of the geology to be tunnelled through, the self weight and strength of the pipes, the diameter of pipe, the type of excavation method, and the available jacking reaction. The major constraint will be the nature of the ground and the ground water characteristics. However, the distance that can be achieved is optimised by the use of a range of techniques.

Intermediate jacking stations

In order to redistribute the total required jacking force on the pipeline, intermediate jacking stations are frequently used between the launch pit jacking rig and the tunnelling machine. A special twin pipe set incorporating an increased length steel collar which slides over a corresponding length spigot detail is introduced into the pipeline. Hydraulic jacks are placed between the two opposing pipes such that when activated they open the gap between the leading and trailing pipes. The inter-jack station is then moved

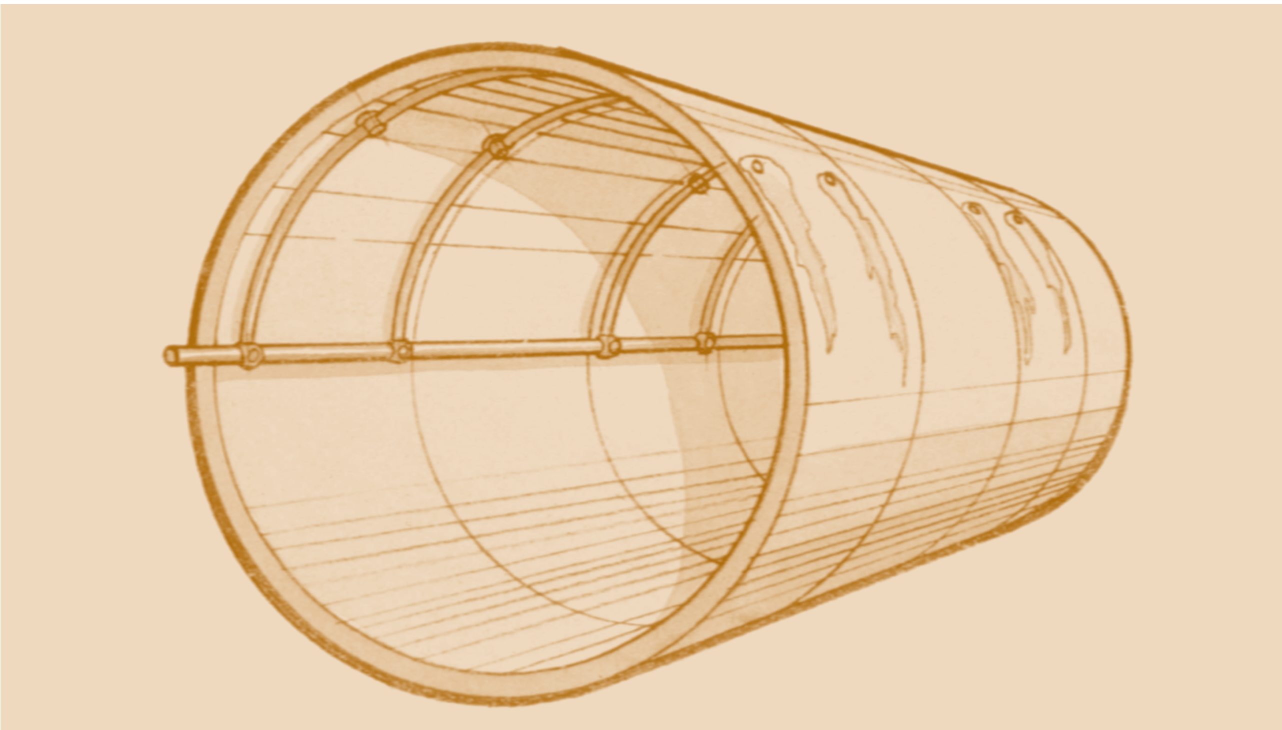
forward with the pipeline in the normal way until it becomes necessary to supplement the jacking forces available from the shaft. On reaching the design value or when the available thrust force is insufficient to move the pipeline forward, then the pipes behind the intermediate jacking station are held stressed back to the thrust wall in the launch pit. The jacks in the intermediate jacking station are then opened, thus advancing the forward section of the pipeline.

At completion of the stroke of the inter-jacks, the main jacks in the thrust pit are actuated, advancing the rear of the pipeline to its original position relative to the leading pipes, and thereby closing the intermediate station jacks. The sequence is then repeated for the duration of the pipe-jack and, on completion, the jacks and fittings are removed and the inter jack closed up.

Inter jack stations are not only used to increase the jacking lengths achievable, but also to reduce the loads that are transmitted to the shaft structure. This is useful where ground conditions at the drive shaft are poor or of low inherent strength.

Lubrication

The pipe jack shield or machine is designed to produce a small overbreak to the external diameter of the pipeline. By injecting a lubricant into this annulus the pipeline can, in theory, be jacked freely through a fluid medium.



Typical lubrication arrangement

In practice, however, fluid losses may occur into the surrounding ground. Providing these can be controlled, the technique results in considerable reductions in jacking forces and therefore longer jacking lengths.

Jacking loads

Loads required to jack the pipeline forward are mainly a function of frictional forces built up around the pipeline. These forces depend on the type of ground and, in particular, its arching characteristics, friction angle, the depth of overburden, the depth of the ground water and any surcharge load, the length and diameter of the pipe being jacked and the time taken for the operation.

Whilst it is difficult to accurately assess these forces using soil mechanics theory, pipe jacking contractors have, after years of experience, derived empirical values. As a guide, frictional forces fall between 0.5 and 2.5 tonnes per square metre of external circumferential area. The use of sophisticated lubricant injection techniques can reduce frictional forces to as little as 0.1 tonnes per square metre.

Frictional forces on the pipeline may be reduced by applying a suitable lubricant, under a nominal pressure above that of the ground water pressure present. If high frictional resistance is anticipated, it is recommended that intermediate jacking stations are placed at regular intervals in the pipeline.

These jacking loads must be resisted by a jacking reaction built up within the thrust shaft. This is normally achieved by the construction of a thrust wall at the back of the thrust pit designed to withstand the anticipated jacking load and to suitably transfer such loading through the shaft structure to the surrounding ground.

Jacking tolerances

In stable, self-supporting, homogenous ground, the acceptable tolerance for man-entry pipes is ±50mm of a true line and ±50mm of true level at any point in the drive. For microtunnelling, tolerances of ±25mm in line and level are attainable. However, in some ground conditions, particularly unstable ground or where obstructions are present, these tolerances may not be readily attainable. In such circumstances where this tolerance or a finer one must be achieved, larger pipe sizes can be considered. Adjustments to line and level should be gradual to ensure that the pipe manufacturer's stated permitted angular deflection is not exceeded at any individual joint.

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