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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Use of trenchless techniques for the construction of underground infrastructures for telecommunication cable installation

ITU-T Recommendation L.38

(Previously CCITT Recommendation)

ITU-T L-SERIES RECOMMENDATIONS

CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

For further details, please refer to ITU-T List of Recommendations.

ITU-T RECOMMENDATION L.38

USE OF TRENCHLESS TECHNIQUES FOR THE CONSTRUCTION OF UNDERGROUND INFRASTRUCTURES FOR TELECOMMUNICATION CABLE INSTALLATION

Summary

This Recommendation describes the main techniques which allow installation of underground telecommunication network infrastructures minimizing or eliminating the need for excavation. These techniques, commonly known as trenchless or no-dig techniques, create a horizontal bore below the ground in which the underground infrastructure (ducts, pipes or direct buried cables) can be placed.

Trenchless techniques can reduce environmental damage and social costs and at the same time, provide an economic alternative to open-trench methods of installation.

After a description of the available techniques, this Recommendation examines the different kinds of work that are performed, the preliminary operation that shall be carried out, the drilling operation and the installation procedure advising on general requirements.

Source

ITU-T Recommendation L.38 was prepared by ITU-T Study Group 6 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 24th of September 1999.

FOREWORD

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The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

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NOTE

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As of the date of approval of this Recommendation, the ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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Recommendation L.38

USE OF TRENCHLESS TECHNIQUES FOR THE CONSTRUCTION OF UNDERGROUND INFRASTRUCTURES FOR TELECOMMUNICATION CABLE INSTALLATION

(Geneva, 1999)

1 Scope

This Recommendation:

- makes a classification of different kind of works that are performed;
- describes the preliminary operations;
- describes the drilling operation and installation procedures requirements;
- describes situations where trenchless techniques are recommended.

2 Available techniques

A broad classification of the available trenchless techniques is given in Table 1. A more detailed description of each technique is reported in Appendix I.

Table 1/L.38 – Classification of trenchless techniques

Guided boring/directional drilling	• Fluid-assisted boring • Dry boring	
Impact moling		
Pipe ramming		
Pipejacking		
Microtunnelling	• High strength pipe method	* Penetrating method * Auger excavation method * Slurry method * Slurry pressure balanced method * Boring method
	• Low strength pipe method	* Penetrating method * Auger excavation method * Slurry method * Slurry pressure balanced method * Boring method

3 Kinds of work

The following work classification is performed in order to give advice on the best equipment to use, depending on the different operational needs.

3.1 Long sections

Trenchless techniques can be used to install underground ducts along the roads as an alternative to traditional digging techniques. Long installation lengths can be achieved (several km) by dividing the work length into shorter sections (100-200 m as an average). The length of each section will depend on the characteristics of the machines and the design requirements.

It is recommended:

that guided boring/directional drilling (both fluid-assisted and dry boring) machines be used for this particular application.

3.2 Crossings

River and railway crossings were the first applications of no-dig technology due to the fact that traditional digging techniques were not suitable. Surface-launched machines are often the best solution because obstacles can be crossed with a curved drilling path, thus avoiding the need to excavate deep launch and reception pits (especially in river crossings). It is possible to consider two different kinds of crossing with respect to the length and to the depth of the installed duct.

– Road and railway crossings: the length of the drilling is normally not very long. For these situations

  it is recommended:

  that both fluid-assisted and dry directional drilling machines be used or the use of microtunnelling systems depending on the duct diameter.

– River crossings: the length and the depth of the bore normally required are very long and deep and it is important to avoid the excavation of big launch and reception pits on the opposite sides of the river. For these situations:

  it is recommended:

  that the drilling is started directly from the surface using a fluid-assisted directional drilling system.

3.3 Urban environment

This represents one of the most attractive applications of no-dig technology because it could avoid or drastically reduce the troublesome drawbacks normally created by digging work in urban areas. Due to the small diameters of the ducts and the short distance of each drilling section (manholes or chambers are normally very close together),

it is recommended:

that a small and dry directional rig is used, in order to reduce the overall dimension of the working site, and to avoid flooding of the drilling fluid along the drilling path and the use of microtunnelling systems, depending on the duct diameter.

4 Site investigation

Exhaustive knowledge of the work site and of the subsoil, right from the first design phases is essential, both to reduce the number of failures and/or to limit possible damage to pre-existing services or structures and to minimize horizontal digging costs by use of the various no-dig techniques.

It is therefore recommended that:

• The drilling plan shall be accompanied by a series of information of the following kind:
  – statutory/administrative;
  – technological (e.g. presence of utilities or obstacles);
  – geolithological, hydrogeological and geotechnical.

Most of this information can be acquired by consulting pre-existing documentation of work carried out in the area (e.g. laying of utilities, etc.).

- Maximum care shall be paid to public utilities which are potentially dangerous (e.g. gas mains) or of public importance (e.g. hospital telephone lines). Further essential information on important or potentially dangerous circumstances may sometimes be obtained from the contracting company which executed the work.
- The following information on the services or structures is also necessary:
  – materials (PVC, metal);
  – diameter, single or multiple;
  – planned and/or real depth of emplacement;
  – infill materials (rubble, sand).
- It is sometimes necessary, when working with documentation made available by local authorities or other companies, to distinguish between "planning" and "as installed" drawings.

Due to these reasons, in order to get precise information on the location of existing buried utilities,

it is recommended that:

a direct on-site investigation should definitely be performed using appropriate equipment.

Pipe and cable locators can detect metallic pipes, current carrying electrical cables and telecommunications cables. Ground Penetrating Radar systems give greater information often detecting non-metallic pipes, cables, zones of leakage and sub-surface discontinuities such as road construction layers or rock strata.

Complete information about soil conditions can be obtained by conventional trial-holes and borings.

5 Preparatory steps

5.1 Use of trenchless techniques not requiring the excavation of a launch pit

For trenchless techniques not requiring the excavation of launch and reception pits,

it is recommended that:

- before starting the work it is necessary to make an accurate evaluation of the available space close to the starting point, taking into account the dimension of the equipment to be used;
- when drilling fluids are used, the overall dimension of the truck carrying the pump and the tanks which are connected to the drilling machine shall be taken into account;
- when positioning the machine, it is necessary to consider the angle of incidence of the first rod with respect to the ground. This angle should not exceed 20° and consequently the drilling machine has to be placed at a suitable distance far from the starting point;
- if drilling fluids are used it is necessary to dig a small pit around the starting point to recover the mud produced by the drilling operations;
- in order to be able to monitor the pilot-bore position from the surface during the drilling operations, the drilling head should be equipped with sensors for measuring the following parameters:
  – depth;
  – inclination;
  – orientation;
  – temperature.

- when using the walk-over system (see Appendix I), it is necessary to calibrate the gain of the receiver, according to the manufacturer's instructions, before starting the drilling of the pilot bore;
- it is also advisable to mark the drill pipes in line with a definite position of the drilling head (e.g. with the angled face up). This will enable the operator to judge the actual orientation of the drilling head during the boring of the pilot hole.

5.2 Use of trenchless techniques that require the excavation of a launch pit

5.2.1 Impact moling

When using the impact moling technique, once the desired route has been established, and before starting the creation of the bore,

the following operations are recommended:

- a launch pit and a reception pit are first excavated at the ends of the bore path, that are a little deeper than the planned depth of installation;
- the launch cradle, if used, is then set up; alternatively the mole can be positioned directly on the floor of the launch pit;
- using a ranging rod in the reception pit and a sighting telescope in the launch pit, the initial line of the bore is established by physically aiming the mole towards the ranging rod target;
- the mole is launched and allowed to advance a short distance. The line is checked for a final time before the whole body of the mole enters the ground. If the line is not correct, the bore is restarted.

5.2.2 Pipe ramming

When pipe ramming systems are used, *the following preliminary operations are recommended*:

- a typical ramming operation requires the establishment of a solid base, normally a concrete mat, on the launch side of the installation. This mat will usually be positioned in a starting pit or alternatively against the side of a slope;
- guide rails set to the line of the bore should then be installed on the mat;
- after positioning the first length of steel pipe on the guide rails, a cutting edge has to be formed or fitted to the lead end of the pipe, and the ramming hammer is attached to the rear of the pipe;
- depending on the diameter, inserts may have to be used to ensure solid and uniform contact between the hammer and the pipe.

5.2.3 Microtunnelling and pipejacking

As far as microtunnelling and pipejacking projects are concerned, particular care shall be taken in preparing the launch or drive shaft.

Drive shaft requirements vary greatly depending on the machine being used, ground conditions, pipe length and material, length of drive and type of installation. They may be round, rectangular or oval; sheet piled, segmentally lined, of special construction or even unsupported if ground conditions are good enough and local safety rules permit; 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 the reaction surface 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 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.

It is therefore recommended that:

- the thrust wall shall 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;
- the shaft shall be constructed to be watertight, particularly in deep and difficult soil conditions, to minimize disturbance of the soil outside the shaft. A watertight shaft also minimizes uncontrolled drainage and dewatering of the zone around the shaft;
- the floor of the shaft needs to be set at the correct grade and be structurally strong enough to support all the microtunnelling equipment. The floor shall be structurally isolated from the shaft thrust wall;
- the thrust wall shall be constructed perpendicular to the direction that the pipe is to be installed and of sufficient structural capacity to transfer the jacking loads through the shaft wall and into the soil;
- even when the exit point of the shield is directly out of the ground at a set position, a reception arrangement shall be designed in order to prevent environmental contamination by loss of lubricant or slurry, or to prevent the ingress of water into the pipeline.

6 Drilling operations

6.1 Guided boring/directional drilling

The work may be divided into different phases, listed in the following paragraphs.

6.1.1 Pilot bore creation

It is recommended that:

- the location of the starting and arrival points shall be planned as a function of the drilling machine performances, in order to optimize the total number of drilling sections;
- in the case of crossings, when the new duct shall be connected with an existing infrastructure, the position of the starting and arrival points shall be determined as a function of the position of the existing manholes or chambers, taking into account the allowable bending radius of the drilling pipes and the duct to be installed;
- in the case of work in an urban environment, the drilling shall be performed behind the sidewalks, to limit possible drawbacks to traffic whenever possible;
- in the case of work in an urban environment, the use of drilling fluids, which could leak into the basement of adjacent buildings, shall be strictly avoided;
- when using the walk-over system, an operator shall follow the pilot bore progress from the surface, by means of the locator, once the drilling has started;
- when the planned depth is reached, the bore shall be performed following a horizontal line parallel to the ground surface. During this step it is advisable to read the data on the receiver at least every 5 metres and to mark the ground in line with the detected position of the drilling head so that the final position of the installed duct will be immediately shown (e.g. for updating a utility map of the area);
- when the walk-over system is used in combination with mud motors equipment, it is necessary to consider that, due to the position of the sonde relative to the drilling head, the data detection can only take place at 1 or 2 metres from the head, requiring the operator to anticipate the direction to take;

- if a remote control unit for the drilling machine is not present, the operator who follows the pilot bore progress (locator) shall communicate the progress to the machine operator (driller), who needs this information in order to control the drilling direction;
- in the case of particular crossings (such as rivers and highways), it is not always possible to follow the progress of the drilling head by means of a locator from the surface. Even if a hard-wire tracking system is used it is advisable to use all the other available data, such as the length of the drill pipes and the last parameters measured by the sensors inside the drilling head (depth, inclination and rotation), to determine the drilling path;
- approaching the arrival pit, the drilling head shall be raised up gradually to reach the final point with an inclination similar to the starting one (max. 20 degrees);
- once the drilling head surfaces at the exit point, a measurement shall be made to determine if the actual exit is within the allowable tolerances. If a portion of the bore is out of the given tolerance, the drill string shall be pulled back and this segment of the bore can be re-drilled.

6.1.2 Reaming and pullback

In certain installations, the pipe can be pulled straight into the pilot hole after it is completed. However, in most installations, the bore will require reaming to enlarge the hole to accommodate the product pipes. In this case,

it is recommended that:

- when the pilot bore is completed, the drilling head is substituted with a reamer which is pulled back inside the bore to enlarge its diameter. To allow correct installation, the internal diameter of the bore shall exceed the maximum external diameter of the duct (or of the bundle of ducts) by at least the 20%. This is necessary to allow for an annular void for the return of drilling fluids and spoils and to allow for the bend radius of the product pipes;
- sometimes more than one reaming operation is required to perform a sufficiently large bore. In this case, a second drill string shall be connected to the reamer using a swivel joint. The rods are pulled inside the bore, so that when the reaming operation is completed they can be used immediately to pull back another reamer;
- when the required bore diameter is obtained, the drill pipe shall be connected to the product pipes using a pullhead or pulling eye and a swivel. A reamer shall also be placed between the pullhead and the drill string to ensure that the hole remains open and to allow more lubricating fluid to be pumped into the hole during the pullback;
- during the pullback phase, it is necessary that the ends of the duct/s are sealed to avoid the ingress of mud and dirt;
- if a single bore is not sufficient to house the ducts that shall be installed, a second bore shall be performed. In this case, it is necessary to maintain a certain distance between the first and the second bore in order not to damage the installed duct/s. This distance depends mainly on the diameter of the ducts but it is advisable to maintain a distance of at least 1 metre between the two bores;
- if the duct terminations are directly buried, they shall be signalled with surface or buried markers;
- the termination of all the installed ducts shall be sealed in order to avoid the ingress of mud and dirt;
- depending on the diameter, the pipes that have to be installed are supplied wound on reels or in shorter straight sections. In the second case, in order to pull the pipes inside the bore, it is necessary to joint the different sections before starting the pulling phase and to avoid changes in the external pipe diameter, which could create problems during the pulling phase;

- if two pipe sections are to be jointed inside a pit or a manhole, it is advisable to use mechanical couplers (e.g. plastic or brass couplers), where available. Mechanical couplers allow an hermetic seal which is necessary when using air or water for the subsequent installation of the cables;
- as far as metallic pipes are concerned, the jointing procedures shall follow the recommendations given by ISO 6761 Standard.

6.1.3 Duct inspection

At the end of the installation,

it is recommended that:

the internal diameter be checked, over the whole length of the ducts, in order to be sure that no restriction or obstruction inside the ducts occurred during the pulling phase.

It is possible to simply perform this operation by blowing inside the pipe a light circular probe having a diameter slightly less than the internal diameter of the pipe itself, which will reach the other end of the pipe if no restrictions or obstructions are present. As an alternative, a more precise inspection can be performed using CCTV (Close Circuit Television) system with semi-rigid cable which allows the camera to be pushed up to the pipe from a single access point.

6.2 Impact moling

After determining the initial line of the bore, the mole is launched and allowed to advance a short distance. In order to avoid misalignment with respect to the planned line,

it is recommended:

- that the line be checked for a final time before the whole body of the mole enters the ground;
- that the bore be re-started if the line is not correct;
- using, where possible, radio sondes which can be fitted either to the rear of the impact mole or, in some cases, within the front end. Although rear-mounted sondes give an indication of progress, they provide less useful information than front-mounted units. Depending on the mole size and length, the sonde can be some distance from the penetrating end of the tool and therefore responds much later than a front-mounted sonde to changes in direction and pitch and so give the operator less time to halt the bore and assess the next move. However, nose-mounted sondes have to be far more robust and well protected as they shall withstand the shock of the forces applied to the front of the unit by the hammer action.

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

Moreover, particular attention shall be paid to the installation depth, to minimize or avoid surface damage due to soil compression restrictions.

It is therefore recommended:

that the bore be performed at least one metre deep for every 100 mm diameter of the tool.

As most utility mains and services (except sewers) are laid at depths of less than two metres in most countries, this gives an effective upper limit of 200 mm for impact mole diameters.

6.3 Pipe ramming

To perform the correct use of pipe ramming systems,

it is recommended that:

- as there is usually no means of monitoring the direction of the pipe during operation, it is vital to establish a clear bore path prior to work commencing;
- when using an open-ended system (see Appendix I), the cylinder of ground within the circumference of the cutting edge stays inside the pipe during the bore. Over the short distances normally undertaken with pipe ramming, this accumulation of spoil is not usually a problem. However, for long bores, it should be remembered that the spoil adds to the weight of the pipe string being rammed and will therefore affect advance rates. In some instances it may be advisable to clean out spoil from the pipe during pipe string extension works, to limit the extra burden on the ramming hammer. Depending on diameter, this can be done either manually or by means of a scraper;
- if intermediate cleaning is not required, and the spoil remains in the pipe for the whole bore, it is necessary to remove it at the end of the installation. If pressurized water or compressed air is used on arrival of the pipe at the reception pit, the open end of the pipe shall be sealed with a suitable plug.

6.4 Pipejacking and microtunnelling

Referring to Appendix I for the detailed description of the techniques,

it is recommended that:

the following points be taken into consideration before starting the work:

- the deflection at the pipe joint face shall not exceed 0.5° although deflections of over 1.0° may be permissible for curved drives using appropriate cushioning materials at pipe joints;
- particular care shall be taken by the operator in maintaining as straight a drive as possible to take full advantage of the design loading of the pipe. High deflection will reduce the maximum loading that the pipe string can withstand without fear of pipe failure in the ground;
- the joints between pipes shall not extend outside the barrel of the pipe. In other words, the entire joint shall be contained within the normal pipe external diameter;
- a correct use of lubrication materials and techniques shall be performed to bring a considerable reduction in jacking loads and ground support problems. It may also allow the use of smaller jacking frame, thus minimizing the size of the drive shaft and helping to reduce the overall cost of the project;
- lubricant shall be injected immediately into the annulus created by the tunnelling machine and on a continuous basis throughout the microtunnelling process;
- it is advisable to consult mud experts, prior to start of the microtunnel, to recommend the most suitable lubricants and procedures related to soil and groundwater conditions;
- soil conditions can affect the types and quantities of lubricants that are needed to maintain low friction, therefore it is necessary to be aware of changing soil conditions along the pipe route;
- 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), the "interjack" station option should be considered before reducing the planned length of the work (see Appendix I);

- selection of the proper overcut (the difference between the excavated diameter of the bore and the outer diameter of the shield or pipe), is critical for completion of microtunnelling drives without unreasonably high jacking force or risk of settling the surface. Typical overcut values can vary from 0.7 cm to 3.7 cm on the radius, depending on the diameter of the machine, the depth below the surface and the ground conditions. Even in this case it is advisable to consult soil experts, together with equipment manufacturers, to determine the correct overcut for a given soil condition;
- dewatering the soil that the microtunnelling machine progresses through can have a dramatic effect on overall jacking forces. Dewatering is often necessary for shaft construction and sometimes for achieving exit of the shield from the soil into the shaft. However, dewatering beyond this point has a detrimental effect on the microtunnelling process. It can often cause substantial changes to the soil matrix and it is usually an unnecessary and expensive process in microtunnelling. It is therefore advisable to use dewatering only to prepare the site for microtunnelling and not during the progress of the machine;
- gradual steering of the microtunnelling system during the drive is vital to keep the jacking loads as low as possible. The operator shall continuously monitor the shield's position relative to the required line and grade and use small amounts of steering to keep the microtunnelling shield on line. Sudden steering corrections are not necessary with a correct survey and should be avoided;
- because of the tendency to make immediate and severe steering to correct the position, it is crucial that the machine is launched on the proper line to avoid excessive steering during the first part of the drive.

7 Record keeping and documentation

As utility corridors and existing crossings become more congested with new installations, it is increasingly important to maintain accurate documentation for future reference.

It is therefore recommended that:

drilling logs, or reports, be produced containing:

- position of the installed pipes;
- specific data;
- times and locations;
- soil conditions;
- drilling data such as depth, angle and rate of penetration and utility crossings.

8 Ground conditions

8.1 Guided boring/directional drilling

The capabilities of guided boring machines can vary considerably according to the type of ground through which they are drilling. In general, homogeneous clays are the most favourable soils. Sand can present problems especially if it is below the water table or is not self-supporting. Gravel can be penetrated at the expense of accelerated wear to the bore-head. In the case of gravel, it is essential to use mud as it holds the tunnel walls.

To choose a suitable technique for the type of ground, the following advice and the classification given in Table 2 should be taken into account:

- standard machines without percussive action or mud motors are generally unsuitable for penetrating rock or hard inclusions;

- mud motors powered by the drilling fluid, double tube and head casing systems, can be used to drive rock cutting heads;
- a way of improving performance in hard ground is by the use of percussive action in conjunction with forward thrust and rotation;
- percussion allows improved penetration and directional control in stony soils or weak rock, but is not intended for drilling through solid rock or large masses or very hard material such as concrete;
- dry boring machines which use a combination of percussion and thrust and rotation actions, with water mist lubrication, enable the penetration of hard rock formations;
- fluid-assisted boring has greater versatility in terms of ground conditions and the maximum diameters can be achieved. However, it requires more equipment and involves dealing with mud-filled excavations and the disposal or recycling of materials;
- dry boring is essentially a displacement technique. As such, it is best suited to compressible, self-supporting soils and may not be appropriate for sands and gravels at bore diameters above about 75 mm. The risk of surface damage shall also be considered, especially in granular soils.

Table 2 gives a general classification of suitable directional drilling systems with respect to different types of ground (see also Appendix I).

Table 2/L.38 – General classification of guided boring/directional drilling techniques (see Appendix I) with respect to the type of terrain

Type of ground	Drilling technique
Silt, clay, sand	Low pressure jetting Dry boring
Gravel, marl, spoil, shale, clays	High pressure jetting Dry boring Double tube/head casing systems Mud motors
Marl, spoil, clays, limestone, sandstone	High pressure jetting Double tube/ head casing systems Dry boring (percussion and water mist lubrication) Mud motors
Limestone, sandstone, some granites, spoil, gneiss	Mud motors with tungsten carbide or diamond inserts Dry boring (percussion/rotation and water mist lubrication)

8.2 Impact moling

The compacting action of the impact mole means that, in general, the use of this technique is recommended only in soils that can be compressed or displaced.

8.3 Pipe ramming

Depending on the nature of the ground, ramming can be carried out with either an open or closed-ended pipe. Open-ended ramming is generally preferable. This has several advantages, including lower reaction against the ramming force, since only the cutting edge is pushed into the ground.

Therefore it is recommended that:

- open-ended ramming be used in hard ground, since, due to the small surface of the cutting edge, the soil does not have to be compressible;

- closed-end ramming be used, in case of non-self-supporting ground, because the soil is displaced around the pipe and compacted around the wall of the bore.

8.4 Pipejacking and microtunnelling

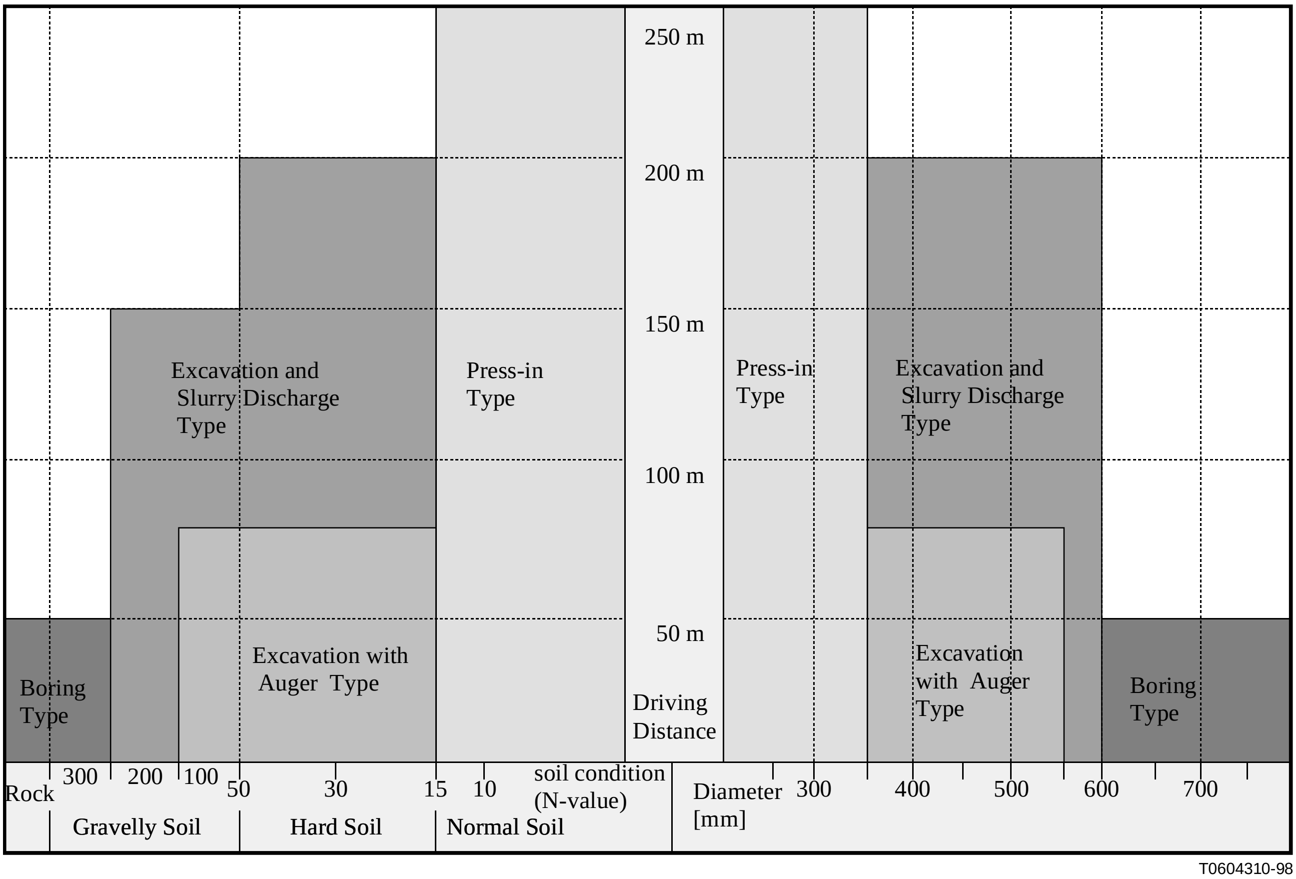
Modern technology has, in recent years, enabled both methods to be applied to a wide range of ground conditions, e.g. waterlogged sands and gravels, soft, stiff, dry or waterlogged clays, mudstones and solid rock.

A classification of the microtunnelling driving methods can be made as a function of their performances in different ground conditions (see Table 3).

In addition, it is recommended that the following points be taken into account:

- the penetrating or press-in method should be used only in soil that can be compressed;
- the auger excavation method can be applied to a wide range of soil quality by selecting the appropriate excavation head. However, the driving machine has an open tip, making it unsuitable for crumbly soil;
- the slurry method can be applied to a wide range of soil qualities from crumbly and extremely soft soils to gravelly soils;
- the slurry pressure balanced method has the widest range of applicability. It can even be applied to ground containing gravel and cobble by mounting disc cutters or a cone-shaped crushing head;
- the boring method, by using an ultra-hard bit mounted onto the tip of the inner pipe, can be applied to very hard soil.

Table 3/L.38 – Fields of application of different microtunnelling excavation techniques as a function of driving distance, tunnel diameter and soil conditions



9 Applications

9.1 Guided boring/directional drilling

A typical mid-range, surface-launched guided boring machine has a thrust and pullback capability of between 8000 and 15 000 kg and torque of up to 5000 Nm depending on its rotational speed. Such a machine would, depending on ground conditions, generally be capable of installing pipe of approximately 250-500 mm diameter over distances of between 100 and 350 metres.

The largest directional drilling rigs can have a thrust of over 100 000 kg and are used primarily for long or large diameter crossings under rivers, estuaries, major highways and long sections. At the other end of the scale, compact rigs, for use in restricted spaces, with a thrust and pullback of around 4000 kg, can install pipes up to about 160 mm over distances of up 100 metres. This again depends on ground conditions. Some include the facility to reduce the track spacing for passage through narrow openings.

Dry directional drilling systems, using a cone shaped reamer with tungsten-carbide cutting teeth connected directly to the drilling rods, can perform the installation of a small diameter pipes, ducts or cables (up to about 65 mm diameter).

Dry installation of pipe diameters up to 250 mm require a pneumatically powered reaming hammer on the drilling head.

9.2 Impact moling

Because impact moling is generally unsteered, the technique is most suitable for short bores (up to 50 metres). A straight bore can often be maintained more easily at large diameters. Diameters range from about 45 to 200 mm depending on the pipe or cable being installed.

9.3 Pipe ramming

Pipe ramming is most often used to install new pipelines or casings into which new utilities will be installed. Installation distances are usually quite short – about 50 metres – on average. Steel pipe is used for the casing, as no other material is strong enough to withstand the impact forces generated by the hammer. The technique is often favoured for crossing under railways, road and waterways, Once the steel pipe is installed, it can be used as a pipeline in its own right, or as ducting for most types of pipe or cable.

Bores up to 2000 mm diameter can be installed in suitable ground conditions, using impact ramming hammers of up to 600 mm diameters generating the equivalent of over 2 000 000 kg of ramming force.

9.4 Pipejacking and microtunnelling

Both pipejacking and microtunnelling are well suited to situations where a pipeline has to conform to a rigid line and level criteria. The guidance and control systems allow accurate installation within close limits of the target.

Most microtunnelling drives are straight between shafts, although specialized 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, specific alignment systems (e.g. gyroscopic devices, combination of electromagnetic induction and liquid pressure difference) may be used as an alternative to the usual laser equipment.

The ranges of recommended applicability are given in Table 3.

10 Conclusion

Considering all the information given in this Recommendation and Appendix I,

it is recommended that trenchless techniques be used in the following situations:

– where road surface excavation is restricted or prohibited by administrative agencies, etc. (newly constructed roads, emergency vehicle entrances/exits, etc.);

– where the open-cut method cannot assure safety or would cause risks to traffic and pedestrians;

– where noise, vibration, dust and other pollution are caused by open-cut method;

– where the open-cut method may impede road traffic and thus hinder the business of nearby stores;

– where congested sections where open-cut method may damage the buried facilities of other companies or sections where the presence of buried objects causes significant lack of work efficiency;

– where conduits should be buried at deep locations and open-cut construction would greatly increase the amount of excavated soil;

– where road surfaces use high-grade material which would increase the cost of reinstatement after excavation;

– where road sections with high traffic volumes where work is limited to the night-time hours (lower work efficiency, higher labour costs);

– where open-cut construction would involve extra costs to move historic remains or other items.

11 Glossary

11.1 auger excavation method: Excavation system using a screw conveyor inside the driving machine to remove the spoils.

11.2 hard-wire tracking system: Monitoring system which requires a direct wire-link between the sonde and the receiver.

11.3 interjack station: Ring of hydraulic jacks within a steel framework which is inserted into the pipe string at a strategic point in order to reduce the jacking force on the pipes.

11.4 mole: Machine which bores into the ground.

11.5 mud motor: An hydraulic motor driven by a high pressure mud flow placed into the drilling head.

11.6 N-value: Number of blows necessary for a penetrometer to drive 30.5 cm into the ground by dropping a standard weight from a height of 76 cm (ASTM Standard Penetration Test).

11.7 open-cut method: Construction method which implies the excavation of an open trench.

11.8 swivel joint: Mechanical joint which avoids the transmission of rotational forces.

11.9 walk-over system: Monitoring system which implies that an operator follows the drilling progress from the surface by means of a remote receiver.

APPENDIX I

Available techniques

I.1 Guided boring and directional drilling

Guided boring and directional drilling techniques are used for the trenchless installation of new pipelines, ducts and cables. The drill path may be straight or gradually curved and the direction of the drilling head can be adjusted at any stage during the bore to steer around obstacles or under highway, rivers or railways. Drilling can be carried out between pre-excavated launch and reception pits, or from the surface by setting the machine to drill into the ground at a shallow angle: the latter case will be mainly treated in this Recommendation. In terms of scale and capability, guided boring and directional drilling tend to fall between the techniques of impact moling and microtunnelling. The terms "guided boring" and "directional drilling" are, for the purposes of the Recommendation, interchangeable. The latter term is frequently used to describe the heavier end of the market such as major river, canal and highway crossing often covering long distances, but there is now such an overlap in equipment capabilities that it is probably unnecessary and unhelpful to draw a line between the two.

Installation of the product pipe or duct is usually a two-stage operation. A pilot hole is first drilled along the required path (see Figure I.1a) and the bore is then back-reamed to a larger diameter to accommodate the product pipe (see Figure I.1b). During this second pull-back stage, the product pipe is attached to the reamer by means of a swivel connector and is pulled into the enlarged bore as the drill string is withdrawn. In difficult ground conditions, or where the bore enlargement is considerable, there may be one or more intermediate reaming stages during which the bore diameter is increased progressively.

Equipment capabilities have improved in recent years and the advantages of trenchless technology for new construction have become more widely appreciated. Some utility companies are now prejudiced against using open-cut techniques (particularly in roads) where a no-dig alternative is available. Apart from the obvious environmental benefits of trenchless installation, the relative cost of guided boring has fallen to below that of trenching for many applications, even ignoring the social costs of traffic disruption and delay.

I.1.1 Methods

Most, but not all, guided boring machines use a fluid-assisted drill head which is pushed through the ground on the end of a string of drill pipes. The drill head is usually angled so that constant rotation of the drill string produces a straight bore, whereas keeping the head in one position causes the line to deviate. A sonde or beacon is usually built into the head or fixed close to it and signals emitted by this are picked up and traced by a receiver on the surface, so allowing the direction, depth, and other parameters to be monitored. Hard-wire guidance systems are also used, with the cable running through the drill string, particularly in cases where the bore path cannot readily be traced on the surface (across rivers, for example), or where the depth of the bore is too great for accurate location by the radio-frequency methods. There are also location systems which use magnetometry.

A bentonite/water mix is often used as the drilling fluid or "mud", which carries the debris in suspension and may be filtered through a recirculation system. On completion of the pilot bore, the thixotropic mud stabilizes the hole ready for back-reaming. The service pipe or duct, generally polyethylene or steel, is drawn in behind the reamer as the original bore is enlarged.

In the case of larger machines, much of the work is done by the rotation of the drill string and the torque of the unit is as vital as the axial thrust and pull-back. As with smaller rigs, it is normal practice to drill a smaller pilot hole and then to back-ream to the required diameter while pulling in the conduit behind the reamer, using a drilling fluid to assist the cutting operation and to lubricate and cool the cutting head. The fluid may also power a down-hole "mud motor" for cutting rock and other hard formations, in which case higher fluid flow rates are necessary.

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

An increasingly common feature is the use of percussive action to complement axial force and rotation. This can be achieved either with a percussive hammer at the bore-head, or by generating the percussion at the machine on the surface and transmitting it along the drill string. Either way, this can significantly improve the ability of guided boring machines to punch through difficult ground or hard inclusions.

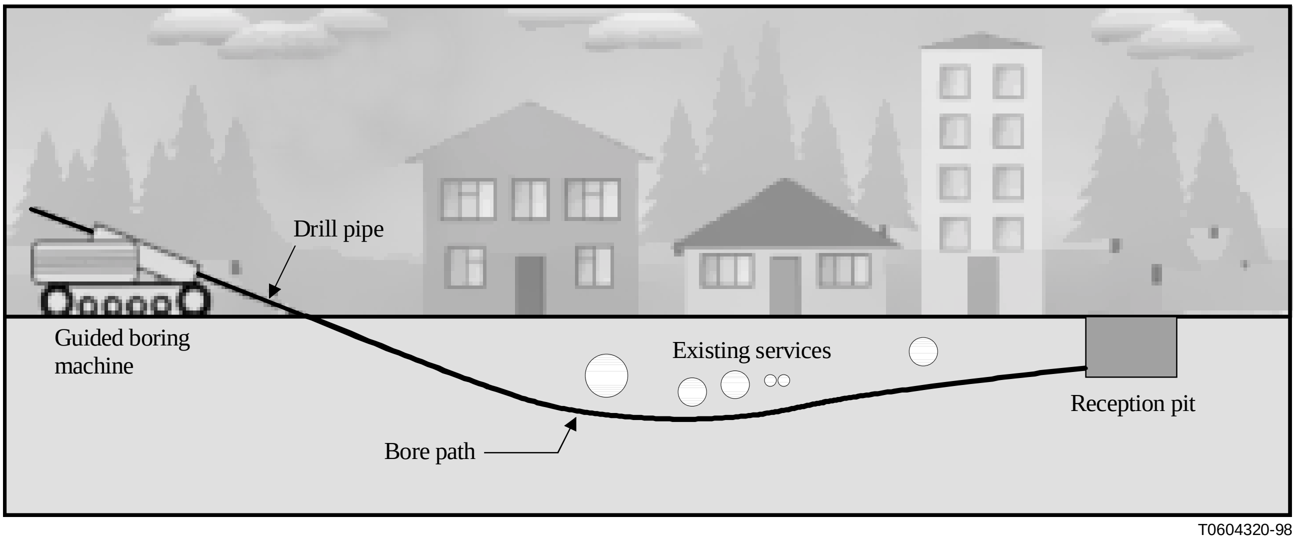


Figure I.1a/L.38 – General scheme of the directional drilling technique: drilling the pilot hole

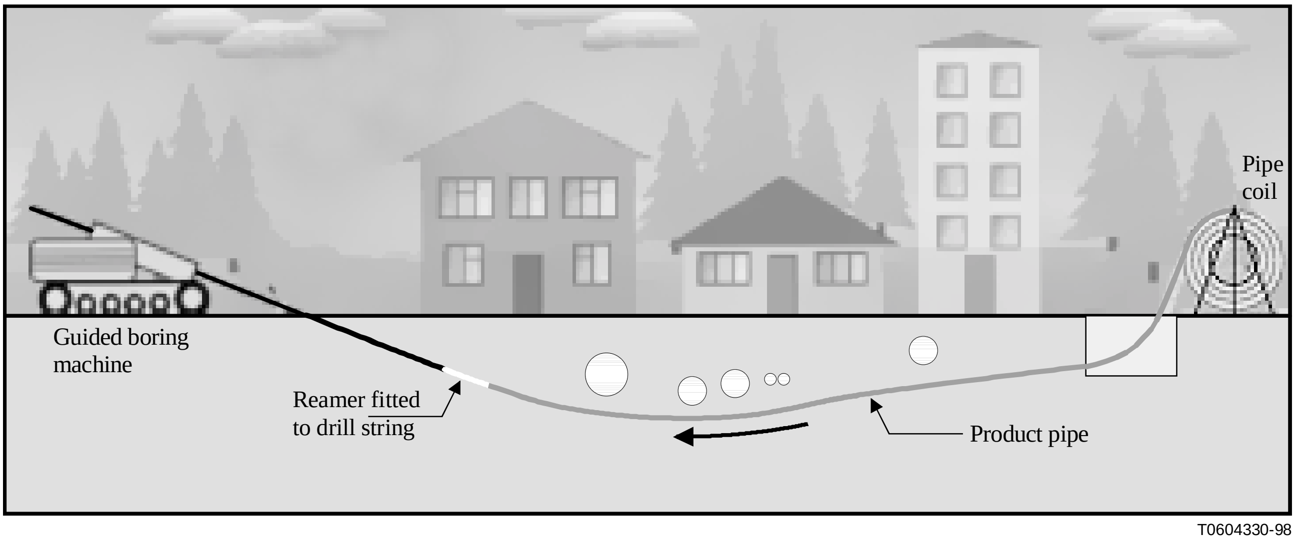


Figure I.1b/L.38 – General scheme of the directional drilling technique: backreaming and pulling in the product pipe

I.1.2 Drilling machines

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

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

Some of the more compact machines can work from an excavation only slightly larger than that needed to make a joint after installation, or directly from existing chambers or manholes. These machines are generally intended to drill fairly straight and often use stiffer drill pipes than surface-launched systems. There are, therefore, greater limitations on their ability to steer around obstacles. The length of individual sections of drill pipe is also restricted by the dimension of the excavation and this may influence the speed of installation and the cost of the drill pipe.

I.1.2.1 Fluid-assisted bore

There are three essential features of any fluid-assisted guided boring machine. The first is a powered rack which pushes the drill string through the ground to bore the pilot hole and then pulls it, and the product pipe, through the bore during the backreaming operation. Typically, the inclination of the rack on a surface-launched rig can be adjusted between about 10° and 20° to the horizontal. The second feature is a motor and drive system to rotate the drill string (together with the attached bore head or backreamer) and provide rotational torque. The third is an hydraulic system to produce a low or high pressure mud jetting which, for some machines, represents the main drilling force.

Pit-launched machines are fixed in position, within the launch pit or chamber/manhole, using their rear and front faces to provide reaction to the thrust and pullback forces.

Surface launched rigs have some form of stake-down system to anchor them to the ground. On the more sophisticated machines, the stake-down system may be hydraulically powered. Some surface-launched machines are self-contained, having on-board mixing tanks and pumps for the drilling fluid, together with associated power supplies, valves and control systems. Alternatively, separate fluid is pumped through the hollow drill string to the bore-head and returns through the space between the drill string and the walls of the bore. The fluid, together with the excavated material mixed with it, is usually pumped into a filtration unit for separation and recycling.

Drilling rigs, especially surface-launched machines, may incorporate an automatic drill pipe loading system in which the lengths of drill pipe are contained in a "carousel" and are automatically added to or removed from the drill string as boring or back-reaming progresses. This may operate in conjunction with an automatic vice arrangement which screws the drill pipes together or unscrews them during back-reaming. Automatic pipe handling is becoming increasingly common, even in smaller machines, since it speeds up installation, improves safety and reduces manpower requirements.

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

Specific fluid assisted systems for rock drilling have been designed: double tube system, "head casing" system, mud motors.

The double tube system uses a double set of coaxial drill tubes. The inner tubes drive the head bit (typically a three cone cutting head) and the reamer, while the outer tubes enable the rotation of a pre-threaded sensor holder to allow the drilling guidance.

As for the double tube set, and also for the head casing system, the principle applied is a mechanical drive to a three cone head via the tube set but, instead of using a second set of coaxial tubes, the head guidance is provided by the position in the ground of an asymmetrical "case" around the first tube that may be locked or unlocked at will and which is used to direct the run in the required direction.

Mud motors are placed in the front of a tube line. They have a bend in them so that they may be directed. An hydraulic motor (rotor and stator) driven by a high pressure mud flow turns the cutting tool (three cone head with hard inserts – carbide or even diamond) located on the mud motor head. Guidance may be performed by cables assembled on the tubes as they progress or by detector.

I.1.2.2 Dry boring

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

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

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

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

Some machines, combining the percussive action of a pneumatic hammer in the drilling head and the thrust and pullback actions, as well as rotation of hydraulics, allow one to perform directional drilling even in hard rock. The high-pressure air which feeds the pneumatic hammer is also used, mixed with very low percentage of water and biodegradable additive (water mist lubrication), to lubricate the drilling tools and the bore, and to moisten and loosen the soil, increasing productivity in dry soil conditions. During the drilling process the compressed air removes all debris, leaving a clean hole and no fluid residue.

I.1.3 Drill pipes

Considerable physical demands are made of the drilling pipes. They should have sufficient longitudinal strength to withstand the thrust and pull-back forces, enough torsional stiffness to cope with the rotational torque of the machine and yet be flexible enough to negotiate changes of direction in the course of the bore. They should also be as light as possible to facilitate transportation and handling, whilst resisting damage due to abrasion and scoring. The length of individual pipes depends on the type of drilling machine and the space available. Typically, surface launched rigs will use pipes up to 4 to 5 metres long, whilst drill pipes for pit-launched machines are often between 1.0 and 1.5 metres in length. Screw joints are most commonly used, although bayonet fittings are found with some systems.

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

I.1.4 Drilling fluids

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

- to lubricate the cutting head and reduce wear;
- to soften the ground so that it is easier to drill through;

- to convey excavated material in suspension back to the launch pit;
- to stabilize the bore prior to backreaming;
- to lubricate the product pipe during backreaming and insertion;
- to power mud motors for drilling through hard ground.

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

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

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

The formulation of drilling fluid is a complex science in its own right and one which plays a major part in the success of projects. Most manufacturers of drilling machines have their own recommendations on the most suitable fluids for particular applications and advice is also available from the manufacturers of the materials. This is an area where specialist guidance should be sought, especially when dealing with difficult ground conditions. The design of a mixing, pumping, filtration and recycling plant is also a major consideration, especially for large-scale projects and again advice should be sought from experienced contractors and manufacturers.

I.1.5 Tracking and guidance systems

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

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

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

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

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

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

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

I.1.6 Ancillary equipment

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

Various types of towing heads for polyethylene pipes are available, including pressure-tight heads and versions aimed specifically at directional drilling. One function of directional drilling towing heads is to prevent the ingress of drilling fluid or debris into the product pipe. Swivel connectors are an essential component during the backreaming and pipe-pulling operation and should be designed to prevent the entry of mud and debris to the bearings. Models are available with capacities from less than 5 to over 200 tonnes.

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

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

I.2 Impact moling

Impact moling, or "earth piercing" as it is commonly known in North America, is defined as the creation of a bore by the use of a tool which comprises a percussive hammer within a suitable cylindrical casing, generally torpedo shaped (see Figure I.2). The hammer may be hydraulic or pneumatic. The term is usually associated with non-steered or limited steering devices without rigid attachment to the launch pit, relying for forward movement upon the internal hammer action to overcome the frictional resistance of the ground. During operation the soil is displaced, not removed. An unsupported bore may be formed in suitable ground, or a pipe may be drawn or pushed in immediately behind the impact moling tool. Cables may also be pulled in.

Although hydraulically driven percussive moles are available, most are powered by compressed air. A potential drawback of air-driven moles is contamination of the product pipe by lubricating oil in the exhaust, although there are methods of overcoming this. Hydraulic moles require two hoses (flow and return) and tend to have greater mechanical complexity.

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

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

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

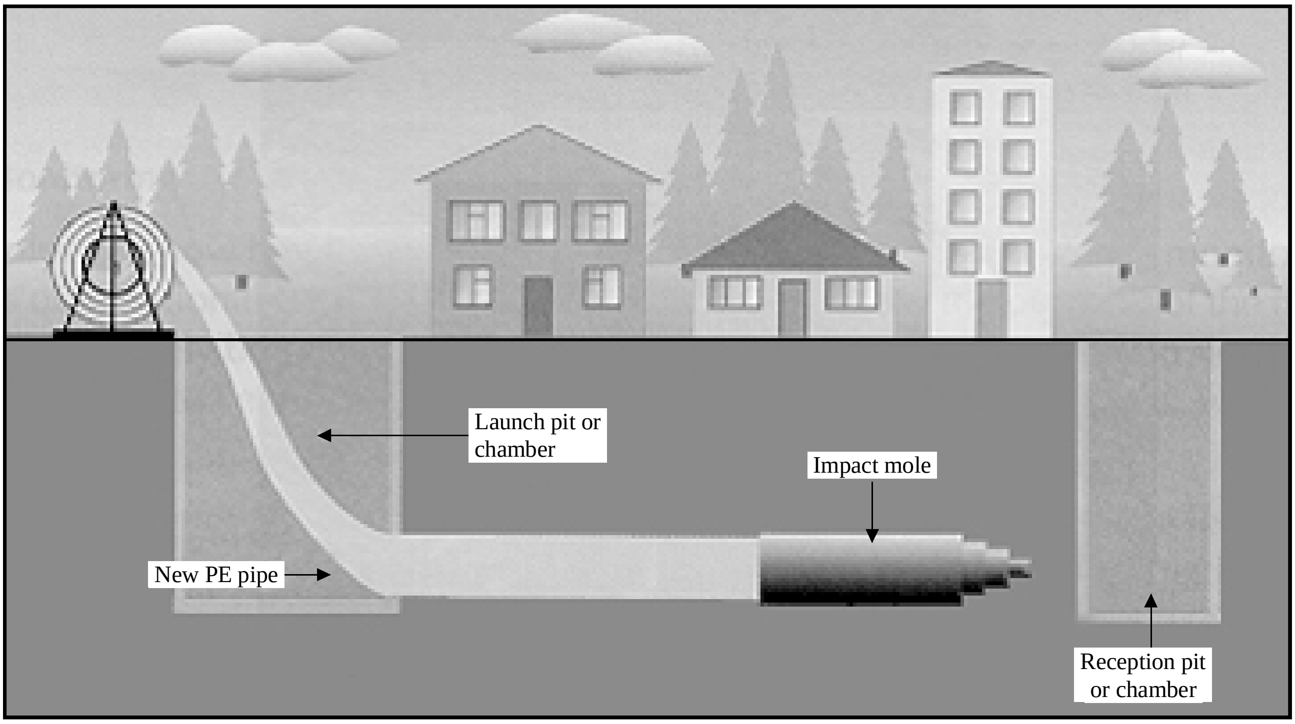


Figure I.2/L.38 – Pipe installation by impact moling

I.2.1 Monitoring

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

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

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

I.2.2 Head types

Two basic head shapes are commonly used for impact moles. The first is the simple cone which, during operation, pierces the ground and pushes the soil aside. The second is the step or chisel head, which is effectively a stepped cone. In normal operation the spaces between the steps fill with soil and the head operates a simple cone. However, when the head strikes an obstacle, the stepped edges concentrate the impact energy against the obstruction. Whereas a smooth cone would tend to be deflected by an obstacle, the stepped shape may apply sufficient longitudinal force to move the obstruction, or shatter it, reducing the risk of going off line.

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

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

I.3 Pipe ramming

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

I.3.1 Set-up

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

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

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

I.3.2 Bore options

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

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

When using an open-ended system, the cylinder of ground within the circumference of the cutting edge stays inside the pipe during the bore. Over the short distances, normally undertaken with pipe ramming, this accumulation of spoil is not usually a problem. However, for long bores, it should be remembered that the spoil adds to the weight of the pipe string being rammed and will therefore affect advance rates. In some instances it may be advisable to clean out spoil from the pipe during pipe string extension works, to limit the extra burden on the ramming hammer. Depending on diameter, this can be done either manually or by means of a scraper.

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

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

I.4 Pipejacking and microtunnelling

Pipejacking and microtunnelling are essentially from the same family of pipeline installation techniques, used for installations from about 150 mm diameter upwards (see Figure I.3). A pipejack is defined as a system of directly installing pipes behind a shield machine by hydraulic jacking from a drive shaft, such that 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 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 utilized.

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

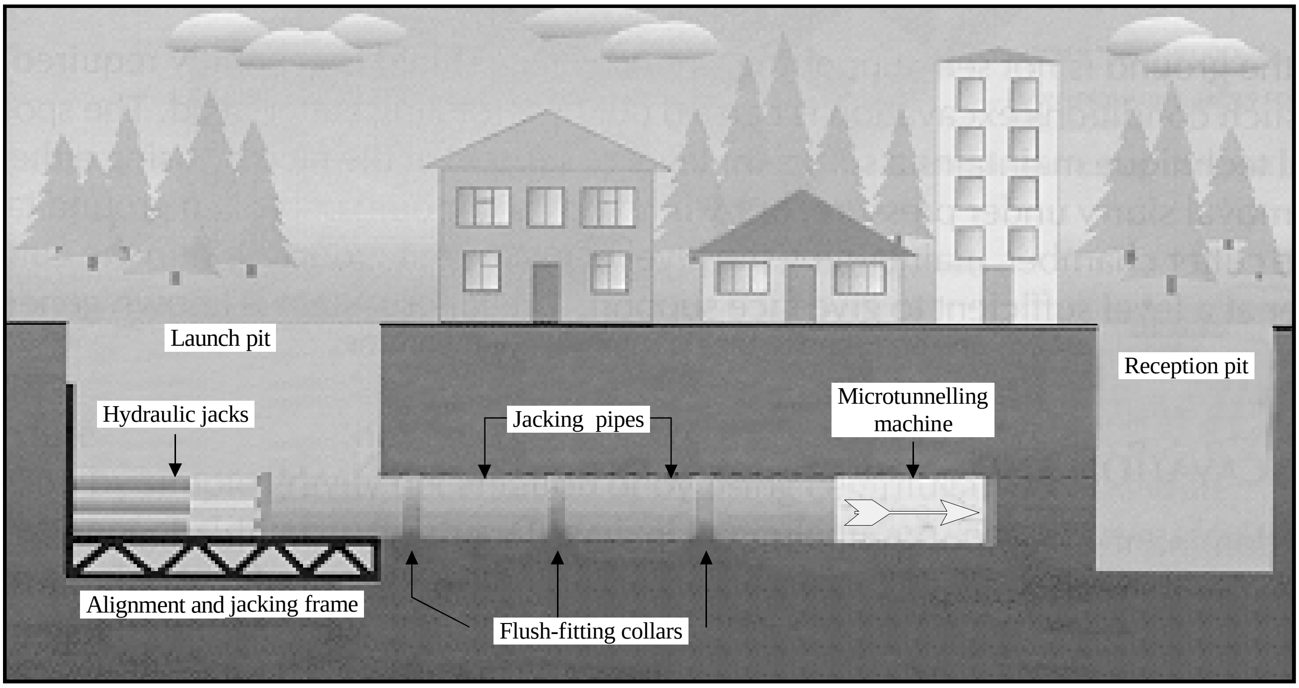


Figure I.3/L.38 – Installing pipes by microtunnelling

I.4.1 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 minimize the number of excavations required, and thus reduce the number of individual drives on any pipeline.

Such planning not only minimizes 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. Optimization 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.

I.4.2 Excavation and spoil removal in pipejacking

Several different excavation techniques are used in pipejacking. 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 utilizes 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 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 within the cutter chamber at a level sufficient to give face support. The latter system is known generally as Earth Pressure Balance.

I.4.3 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 (see Figure I.4).

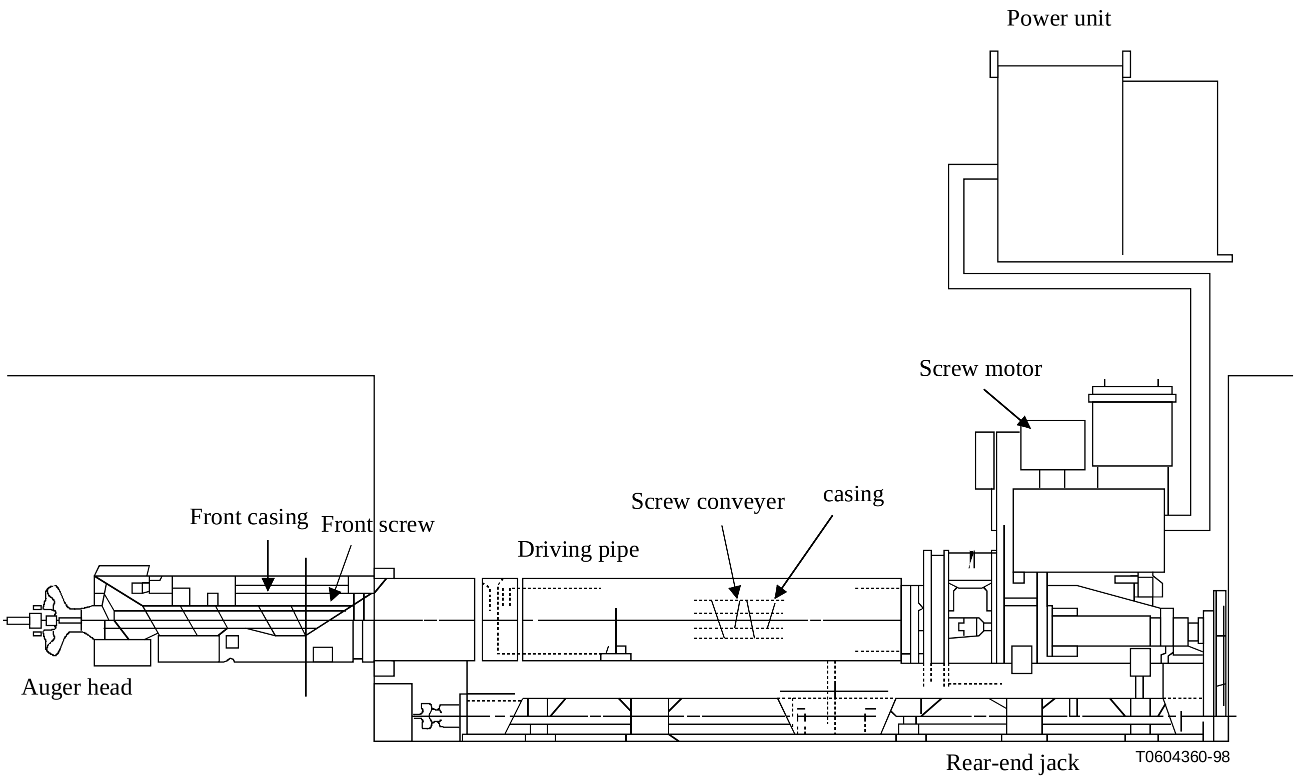


Figure I.4/L.38 – Example of auger excavation method

In more difficult ground conditions, and at higher ground water heads, a recirculating slurry system is often used (see Figure I.5). 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 pressurized 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.

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.

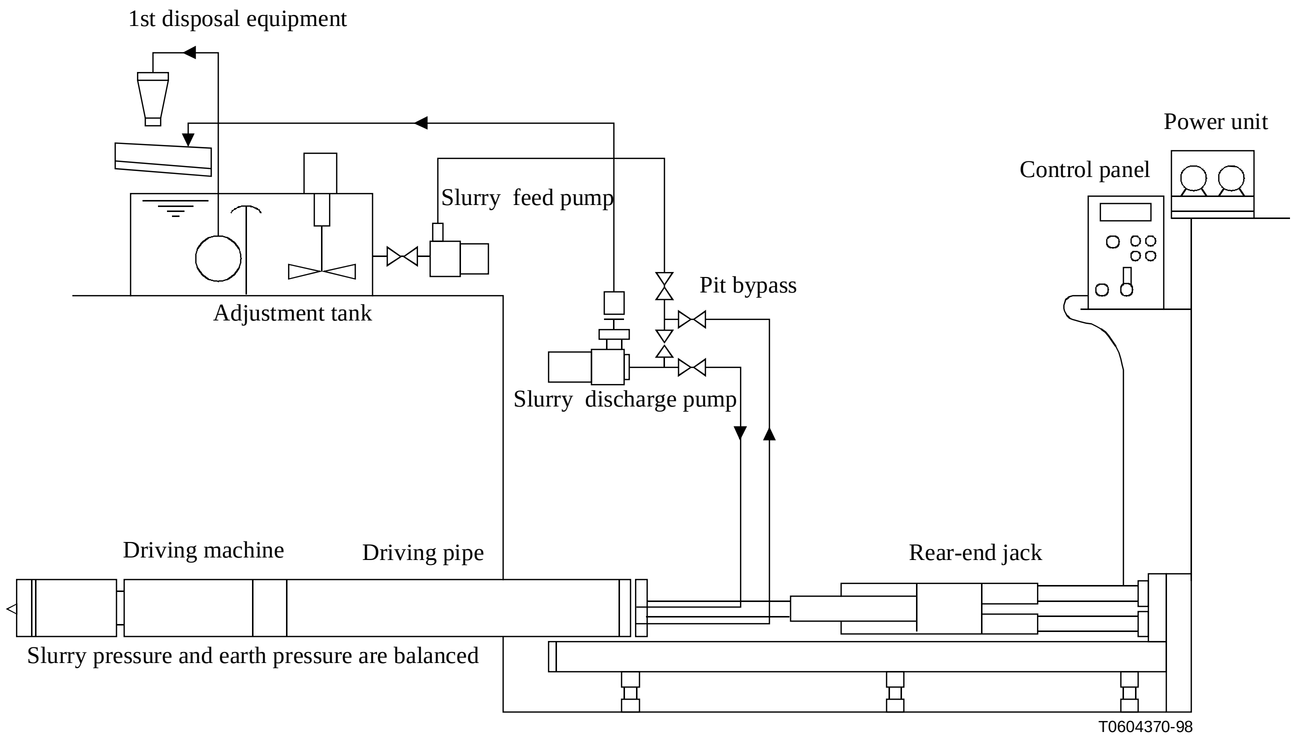


Figure I.5/L.38 – Example of slurry method

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.

There is also a system which utilizes 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.

Some systems use the so called slurry pressure balanced method (see Figure I.6). Such systems mount a pressure balanced slurry discharge type driving machine onto the tip of a driving pipe. Soil is excavated by rotating the cutters while at the same time maintaining the stability of the soil by adopting a water-stopping valve and injecting additives to promote plastic liquefaction of the excavated soil. The excavated soil is mixed with slurrizing water to create slurry which is then discharged in liquid form via a pipe passed through the driving pipe or guide pipe. Like the slurrizing water system, driving is performed while adjusting the amount of additives injected and the driving speed to stabilize the soil. Bentonite or polymer-based additives are selected according to the soil quality.

The water pressure balance method balances the soil using water pressure instead of slurrizing water, and is used for soil with a low water pressure such as water-filled sandy layers.

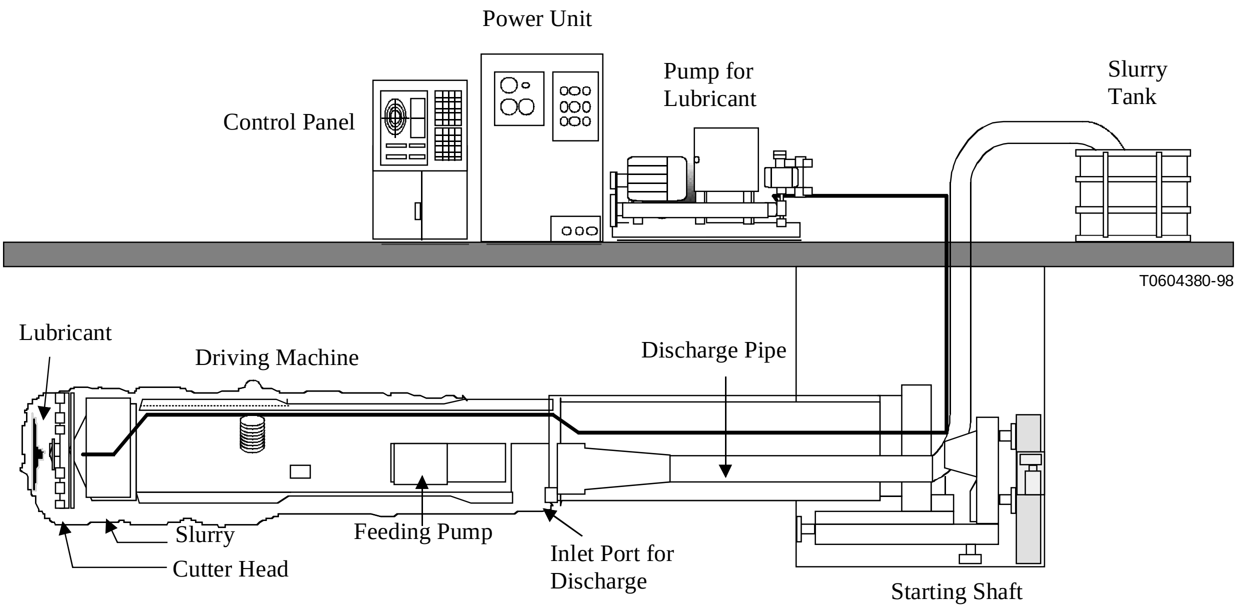


Figure I.6/L.38 – Example of slurry pressure balanced method

Two other specialized microtunnelling techniques are available for bores of up to about 300 mm diameter. The first is a simple compaction method (penetrating or press-in method, see Figure I.7) 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.

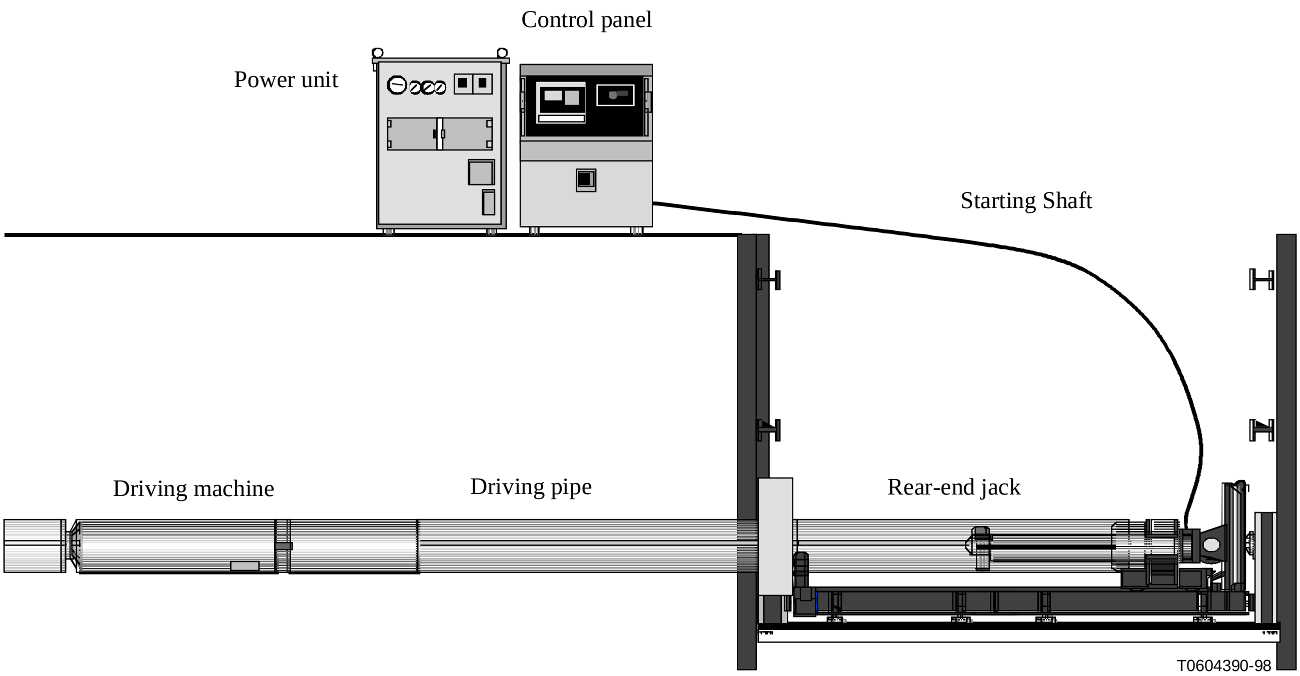


Figure I.7/L.38 – Example of penetrating method

This system is limited to compactable soil types. The second (boring method) employs an 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.

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 abnormal strengths or thrust wall.

I.4.4 Microtunnelling work method classification

Work methods are broadly divided into high strength and low strength systems, depending on the type of driving pipe, and then subdivided further according to the excavation and soil discharge systems. High strength systems transmit the driving force directly to high strength pipes. In contrast, low strength systems pass a driving force transmission rod and a traction rod through low strength pipes and then drive these rods so that the driving force is not transmitted directly to the low strength pipes. Thus, the tip resistance acts only on the transmission and traction rods, and the low strength pipes must bear only the friction between the soil and the outer surface of the pipes (Figure I.8).

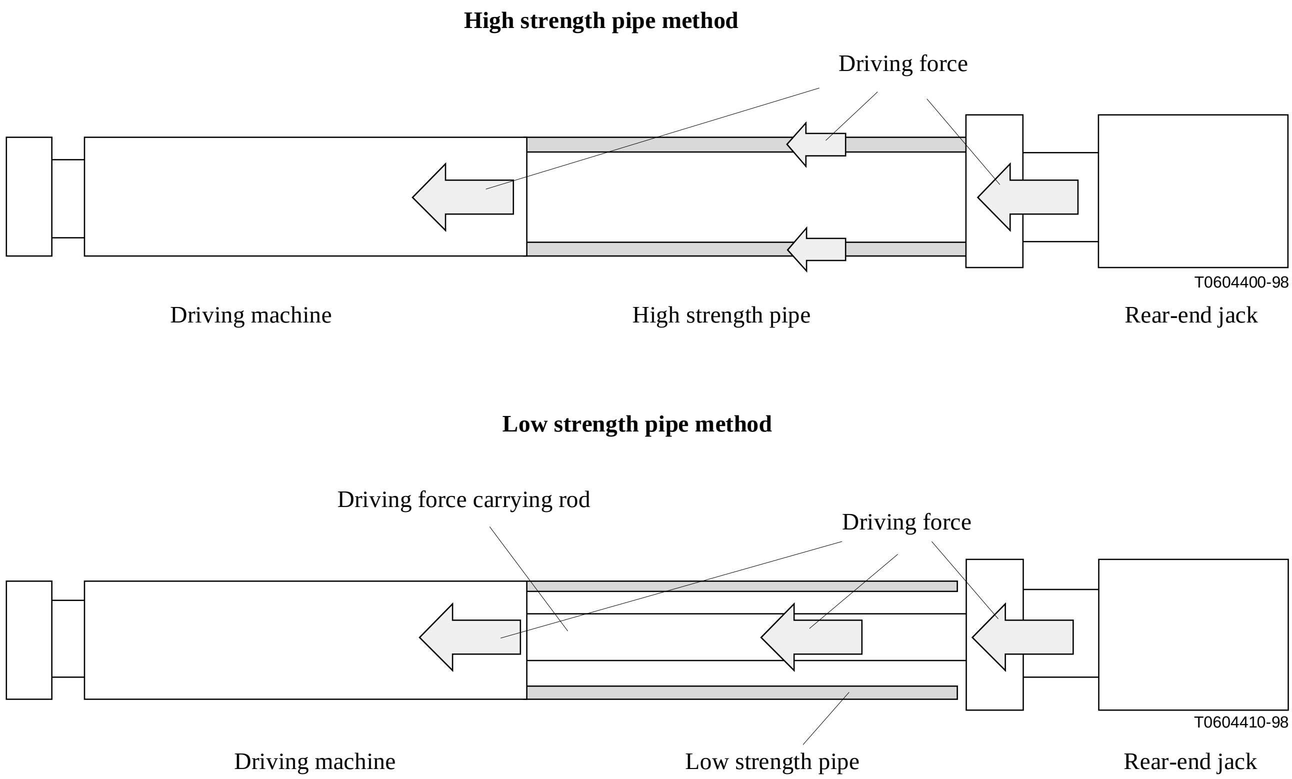


Figure I.8/L.38 – High strength pipe method and low strength pipe method

In addition, there are also single-stage systems in which the driving machine and pipes are directly driven, and two-stage systems in which first the driving machine and a guide pipe are driven and then the conduit pipes are driven along the guide pipe. Two-stage systems generally support wider pipe diameter and driving distance ranges than single-stage systems (Figure I.9).

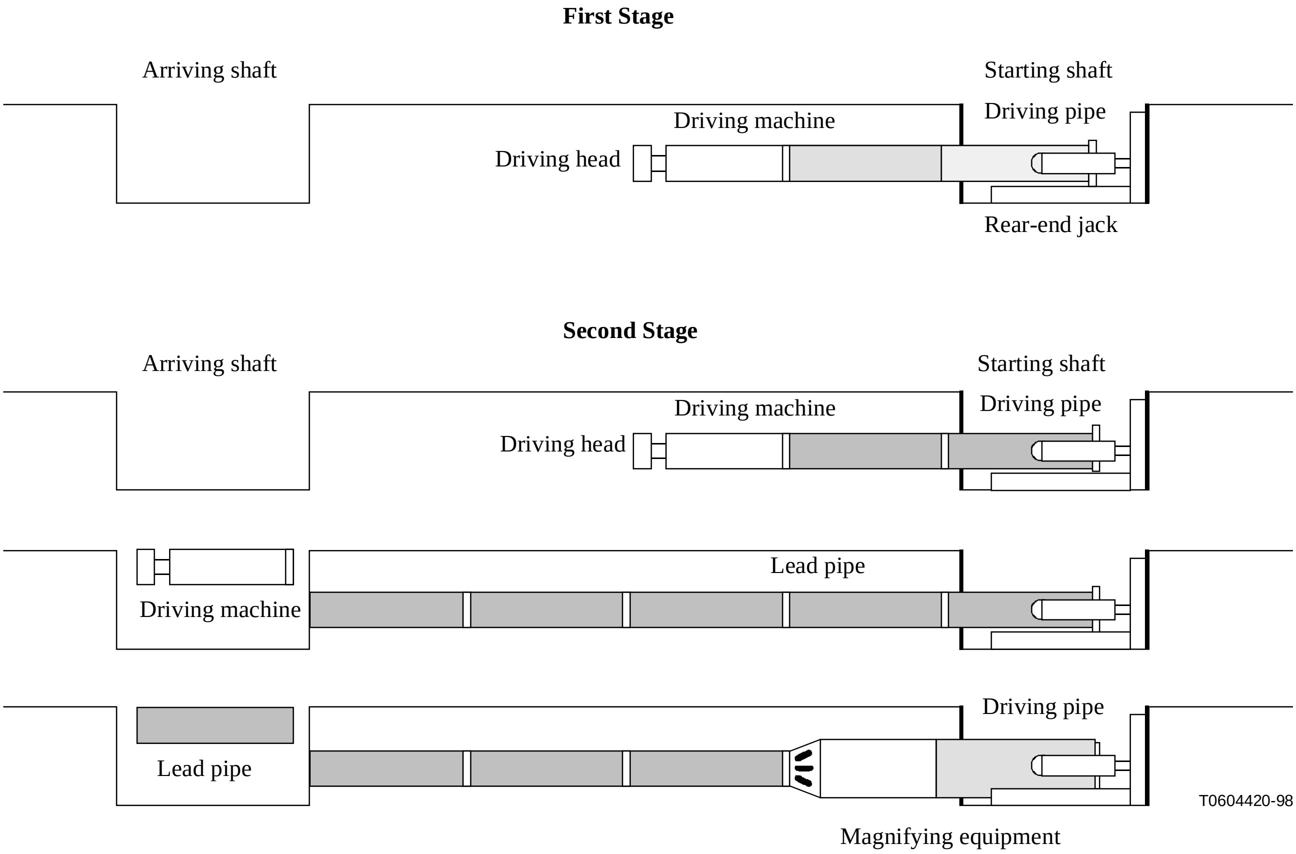


Figure I.9/L.38 – Difference of first stage and second stage

A further classification can be done considering the main driving methods:

- auger excavation method;
- slurry method;
- penetrating or press-in method;
- slurry pressure balanced method;
- water pressure balanced method;
- boring method.

I.4.5 Position detecting methods

The microtunnelling method drives over long distances while controlling the direction, making it important to confirm the position of the driving machine underground.

I.4.5.1 Laser targeting method

A laser beam emitter is set up in the starting pit and a target made of glass or photoreceptors is mounted inside the driving machine. The position where the laser beam strikes the target is then monitored by a theodolite in the starting pit or a CCD camera inside the driving machine. The driving machine inclination can also be sensed by using two target plates. This method enables accurate sensing over straight alignments, and provides a sensing accuracy of within a few millimetres at distances up to about 100 m.

However, when the driving distance exceeds 150 m, the laser beam becomes dispersed and the diameter of the light striking the target increases, resulting in incorrect position indications. In addition, there are also problems such as laser beam refraction due to temperature changes inside the driving pipe.

I.4.5.2 Electric magnetic induction method

This method estimates the position of the driving machine by mounting an electromagnetic coil inside the driving machine and sensing the strength of the electric magnetic field emitted from this electromagnetic coil above ground. This method is capable of measuring the absolute position, regardless of distance or alignment, and could be considered an important technology, for driving over long distances and curved routes, in the future. The sensing accuracy is from several centimetres to within twenty centimetres.

Issues concerning this method are that accurate detection is not possible if there are other electromagnetic fields or objects which disturb or block electromagnetic fields near the driving position, and the electric magnetic field cannot reach the ground surface if the driving position is too deep.

I.4.5.3 Liquid pressure differential method

This method is used to accurately measure the depth of the driving position. The depth is detected by linking pressure sensors, which are inside the driving machine and above ground, with a hose filled with a liquid that has small bulk modules relative to temperature changes, and converting the pressure difference to a depth difference. These pressure sensors are extremely accurate and enable accurate detection to within several millimetres.

Issues concerning this method are that air entering the hose, and differences in the temperature inside the driving machine and above ground, can easily produce error. However, this error can be reduced by constantly circulating the liquid inside the hose and by using temperature correction sensors.

I.4.6 Soil improvement methods

Construction is sometimes difficult to execute safely, or may affect the surrounding ground and structures, depending on the soil conditions. In these cases, an appropriate soil improvement method must be selected, taking into consideration soil conditions, the work environment and other factors, in order to stabilize the soil.

I.4.6.1 Groundwater level reduction method

If pits are located in places with a high groundwater level, water may flow into the pits or phenomena, such as boiling and heaving, may occur. In these cases, wells are dug near the pits to collect and drain away the water. Drainage methods include gravity drainage for highly permeable soil or vacuum drainage for soil which is not so permeable.

Draining water for long periods may cause problems, such as ground subsidence or drying up surrounding wells, so sufficient surveys must be carried out in advance.

I.4.6.2 Chemical injection method

This is a general method for increasing soil strength and improving water-stopping performance. Liquid chemicals with coagulant properties are injected into soft soil, soil with a high groundwater level or other soil needing improvement, via injection pipes, to stabilize the soil and obtain water-stopping effects once the chemicals coagulate.

The type of chemical, and the injection method used, may differ according to the applicable soil quality and permeability.

I.4.7 Jacking frames

Pipejacking 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.

I.4.8 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 directly out of the ground at a set position. 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 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.

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 boulders up to 30% of the machine’s outside diameter.

I.4.9 Pipes

Driving pipes are roughly divided into high and low strength pipes. High strength pipes include steel, reinforced concrete and other pipes which allow the driving force to be transmitted directly to the pipe. Low load resistance pipes include rigid PVC and other pipes which are unable to directly transmit the driving force.

However, 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.

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. The joint face should be manufactured to ensure squareness 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 and 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.

I.4.10 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 inertial surface of the bore.

The problem of friction is most commonly addressed by using pipe of 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 minimizing 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 minimizes 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 minimizing 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.

I.4.11 Interjacks

Where the lubrication of a pipe may not be sufficient in itself to allow successful completion to 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 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.

I.4.12 Jacking loads

The proper execution of a microtunelling project depends on the proper selection of the method, workmanship of an appropriately skilled crew and limiting the unexpected by evaluating and scheduling the process. The ability to predict the jacking loads to an acceptable degree of accuracy can dramatically reduce unexpected problems.

The jacking loads are the forces due to the friction between the external surface of the pipes and the ground (skin friction) and to the face pressure acting on the cutting head.

The jacking loads affect some basic elements of the microtunnelling process: the strength of the pipe being jacked, the capacity of the jacking system to be used, the capacity of the shaft thrust wall to withstand the jacking force and the length of pipe to be installed in a single push.

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