International Energy Agency

Programme of Research, Development and Demonstration on District Heating and Cooling, including the Integration of CHP

Pipe Laying in Combination with Horizontal Drilling Methods

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Preface and Acknowledgements

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries. As an element of the International Energy Program, the participating countries undertake cooperative actions in energy research, development and demonstration.

District Heating is seen by the IEA as a means by which countries may reduce their dependence on oil. It involves the increased use of indigenous or abundant fuels, the utilization of waste energy and improved energy efficiency. With the same objectives District Cooling is getting a growing interest. The positive environmental effects of improved energy efficiency will give an additional and very strong impulse to raise the activities on District Heating and Cooling.

IEA’s Program of Research, Development and Demonstration on District Heating was established in 1983. In the period between 1983 and 1999 under the auspices of the IEA 5 programs were carried out, Annexes I to V.

In May 1999 Annex VI has been startet up. The following countries co-operate in Annex VI: Canada, Denmark, Finland, Germany, Korea, the Netherlands, Norway, Sweden, United Kingdom and USA. The Executive Committee has set following priorities:

- Heat distribution
- Optimisation of a DH system by maximizing building system temperature differences
- Optimised DH systems using remote heat meter communication and control
- Simple models of operational optimisation
- Optimisation of cool thermal storage and distribution
- Absorption refrigeration with thermal (ice) storage
- Promotion and recognition of DHC/CHP benefits in greenhouse gas policy and trading programs
- District heating and cooling building connection handbook

NOVEM is acting as the Operating Agent for Annex VI.
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This report is part of the project “Heat Distribution” with the tasks

- Pipe laying in combination with horizontal drilling methods
- District heating network operation
  Supervision and maintenance
  Mobile methods of shutting down DH lines

The work on the task cold installation has been monitored by the “IEA-Experts Group Cost Effective Networks” (EG) with Dr.-Ing. Frieder Schmitt from “MVV Mannheimer Versorgungs- und Verkehrsgesellschaft Energie AG (MVV Energie AG)”, D-Mannheim, as project leader and chairman of the experts group.

The members of the Experts Group have been:

- Sten Tore Bakken, Norway
- Paul Ramsak, The Netherlands
- Neville Martin, United Kingdom
- Heinz-Werner Hoffmann, Germany
- Manfred Klöpsch, Germany
- Ture Nordenswan, Sweden
- Per Rimmen, Denmark
- Kurt Risager, Denmark
- Veili-Pekka Sirola, Finland

The chairman wants to thank everybody who has contributed and made it possible to carry through this work - especially every individual of the EG for making a good effort and showing a positive will to cooperate.

A special thank to Mr. Nordenswan for valuable contributions of material from Sweden.

Content

1 Summary

Today, the building industry has building methods at its disposal for constructing pipelines without trenches, i.e. in horizontal bore holes. Up to now this construction method has only been applied to district heating pipeline building in the framework of special building measures. However, it now offers itself for standard laying. The new processes have considerable advantages for all involved in the project, as the building times can be considerably shortened and roads must only be opened up at the launching and target trenches. The advantages benefit the local residents, the community and the owner himself. The building costs which are still not cheaper than for conventional building are the main obstacle for a wider application.

Today, trenchless pipeline construction is technically possible in all situations. The most appropriate method must be determined according to the building conditions.

The most suitable drilling methods for trenchless construction are horizontal hydraulic drilling for longitudinal laying of supply pipelines and the drilling method with the earth displacement hammer (earth rocket) for the laying of house service connection pipelines. In the case of horizontal hydraulic drilling the ground is hydraulically worked with a bentonite suspension. With the earth rocket a drill head attached to the pipeline is driven through the ground by a pneumatic hammer.

Horizontal hydraulic drilling is completely mechanised today. The drilling system is mounted on a vehicle; the drilling itself runs more or less automatically. There are systems of various sizes, even small manoeuvrable systems which can be used in yards or gardens. In the report the different drilling methods are described and their properties and limits of application compared one with another.

Compared with conventional construction, the trenchless pipeline construction method involves a higher risk, which can however be kept small if there is careful planning and conscientious operation. Trenchless construction has already proved itself in public supply, mainly for sewage pipes.

Pipeline construction using the earth displacement hammer (earth rocket) is already competitive with conventional construction in open pipeline trenches. There are supply companies who lay house service pipelines using earth rockets as standard practice. On the other hand horizontal hydraulic drilling appears to be only at the edge of competitiveness.

2 General Comments

Pipelines for public supply are traditionally laid in open trenches. However, under difficult laying conditions e.g. for crossing waterways, railway lines, main roads etc. underground building methods have also been used for a long time. These were mostly special measures where costs did not play a part as other considerations took priority.

In the last 20 years, the building industry has further developed underground construction methods considerably and improved their profitability. Compared with the open construction process, the closed building method is so competitive today that, in certain cases of supply and disposal, longitudinal pipelines are being laid without trenches as standard practice and not only for difficult sections of pipeline. The introduction of trenchless construction was led by companies building sewage pipes. The deep position and the large diameter were favourable to underground construction. Today, in the construction of sewage ducts, pipe propulsion is just as important as the open construction method. Meanwhile, even gas networks are being built where the total longitudinal laying is carried out in a closed construction.

In the construction of district heating pipelines, although building sections are more and more frequently being carried out using the trenchless methods, the closed construction method has not yet been introduced for longitudinal pipe-laying under standard building-site conditions. In future, the closed construction will surely gain importance since the effects on road traffic can usually be avoided and such building sites can be organised in such a way that they are particularly environmentally acceptable. The advantages of a trenchless construction are listed in Table 2-1.

Table 2-1: The most important arguments for microtunneling

- Minimum movement of earth, i.e. favourable regarding transport, resources, disposal
- Underground pipelines can be laid in such a way that other pipelines do not have to be moved to another position
- Less disturbance to traffic
- Less annoyance to local population from the building-site and noise
- Reduced impact on buildings and gardens through drainage

Not all terms used in trenchless construction have become clearly defined. Microtunnelling is the general term used for all construction methods for an unmanned and usually remote-controlled pipe propulsion. In addition, the term horizontal directional drilling (HDD) has been introduced. This describes controlled horizontal hydraulic drilling, in which the ground is hydraulically worked, sometimes with the mechanical support of drills, presses or hammers. The most usual terms for underground construction are summarised in Appendix 2.

3 Introduction

3.1 Laying situation

The building sites for district heating pipelines mostly lie in residential areas in towns; only transport pipelines go through open spaces. The effort and expenditure on underground engineering for this type of transport pipeline are relatively low so that there can be no great motivation to use closed construction methods here. Trenchless construction will be applied more frequently in the district heating sector when it offers advantages to building sites in the town.

Supply lines for district heat consist of main pipelines of ca. DN 50 to DN 300 and more, as well as house service pipelines. These are branch pipelines of ca. 8 to 15 m length, with nominal diameters of ca. DN 16/20 to DN 50 and possibly more. As district heating pipelines are fitted with thermal insulation, the external diameter of the pipe is considerably larger than the diameter of the medium pipe and is at least 80 mm for DN 20 and 450 mm for DN 300. Horizontal drillings for district heating pipelines must therefore be larger than drillings for gas or water pipes of the same nominal diameter.

3.2 Advantages of trenchless construction

In the present document, an investigation has been undertaken to find out the advantages, which the methods of underground construction provided by the building industry, can offer for the construction of district heating pipelines. The economic and ecological advantages of trenchless construction of pipelines, as summarised in Table 3-1, have to be considered under the special conditions of district heating. This report has the aim to collect and describe the experiences in the construction of pipeline tunnels, where the methods could have advantages in the building of district heating pipelines. It is intended to help planners and builders of district heating networks to apply these new building techniques which can protect the environment.

Table 3-1: The economic and ecological advantages of closed construction methods

- The expensive restoration of the road surface is no longer necessary
- Faster progress on the building site
- It is possible to tunnel under existing supply systems, so that moving and making the systems safe is more or less unnecessary
- Hardly any danger of settlement; no expensive sheeting constructions
- The domed support function of the road is maintained
- Excavation, transport and disposal is only necessary for the actual volume of the pipes; particularly advantageous in the case of contaminated earth where displacement of soil methods can be used
- No disruption of traffic
- No nuisance to local residents (including shops and businesses)
- Careful treatment of trees, gardens and parks

4 Construction of Pipeline Tunnels

Today, the user has numerous drilling techniques, tested over many years, at his disposal. The systematic descriptions presented here for district heat pipe construction try to bring together the different points of view of all the partners involved in this process. The viewpoint of the manufacturer of the drill itself concerns the technical production, the underground engineering company reviews the process from the pipe builder’s point of view, the supply company primarily assesses the function of the finished product. An important accessory to the drill is the locating device for the drill head. Controlling is only possible by means of orientation. Today’s locating methods work with a measuring tolerance of ca. 5 cm.

The drill can be a simple pneumatic hammer, which is driven through the earth. However, it could be a horizontal hydraulic drill, which presses a swivel on a rod into the earth, and whose flushing system both cuts through the ground and transports the soil out of the hole. The most sophisticated drill is a full-section tunnel drill with a diameter of a few decimetres or of several metres.

Table 4-1 shows an overview of the drilling methods available today which appear suitable for the building of district heating pipelines. This diagram classifies the methods according to the technical drilling criteria.
The first column lists the method according to which principle the cutting process works. These are the earth hammer, which is very often employed, and the horizontal ram. All other methods listed in the overview describe drilling methods in which the soil is removed to build the tunnel.
Column 2 shows uncontrolled drilling methods with earth removal.
(Controlled pressing, which is usually called hydraulic pipe propulsion in district heating pipe construction, is given in column 4.)

Table 4-1: Drilling methods for trenchless laying of district heating pipelines

Holemaking by Displacement	Holemaking with earth removal, dry	HDD Horizontal Directional Drilling	Other methods
earthhammer (earthrocket)	horizontal ramming with open pipe	hydraulic drilling	pipe jacking
horizontal ramming with closed pipe	mechanical boring, directionally uncon-trolled	hydraulic drilling with hammering, pressing	microtunneling
		boring, dry	shield tunneling, manned

directionally controlled: (yellow) no (green) yes

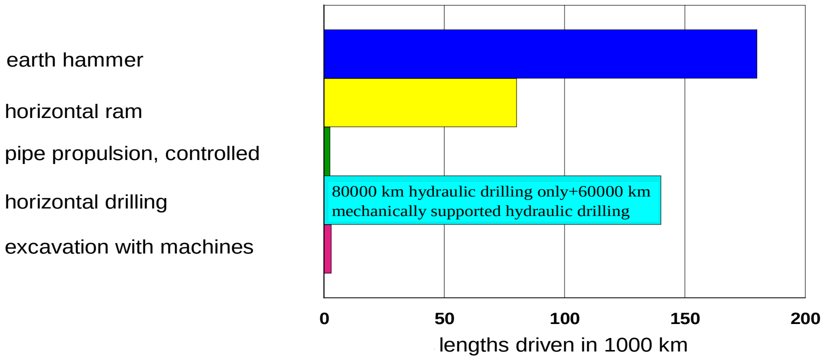
Horizontal hydraulic drilling methods are listed in column 3. Although these are purely horizontal hydraulic drilling processes, which are only suitable for easily workable ground, the most recent of the listed methods has reached a wide dissemination in a very short period of time thanks to its favourable properties and as a result of a strong impulse for further development in the USA and from the gas industry. Horizontal hydraulic drilling is available with a large variety of mechanical aids, should the ground to be drilled through require them. Horizontal hydraulic drilling can be combined with mechanical drills, also with hammers, and presses so that it can also be used in stony soil.

The most sophisticated drilling methods for large pipe propulsion are given in column 4. They are available in the diameter sizes from ca. 200 mm up to several metres. The small machines always work with hydraulic and the larger also with mechanical transport of the soil.
Furthermore, there are other drilling methods, such as the pilot pipe process, mining methods for large tunnels etc.. These will not be handled here in detail. In an individual case it could

happen that a district heat pipeline could be laid economically using the pilot pipe method, however, in the normal case the methods listed in columns 1 to 3 will be better as far as the costs are concerned.

The result of a statistical analysis for Germany in 1996 is interesting as it shows which drilling capacities have been achieved by the different methods up to that time. The distances travelled using the different processes are shown. (The reader must be aware that here completely different drilling methods are being compared only in their drilling distances, that namely the drilling lengths constructed using earth rockets are compared with those built using tunnelling machines. They are extremely different as far as their value is concerned.)

Fig. 4-1: Lengths achieved by the different drilling methods



In addition to the drill, a complete drilling system requires auxiliary equipment, for instance, for energy supply with compressed air or electricity, or for the treatment of the drill suspension or to remove the soil. In addition the building site requires a launch and target trench, the size of which will depend on the drilling method as they have to be made according to the special given requirements, e.g. to take up the compression forces.

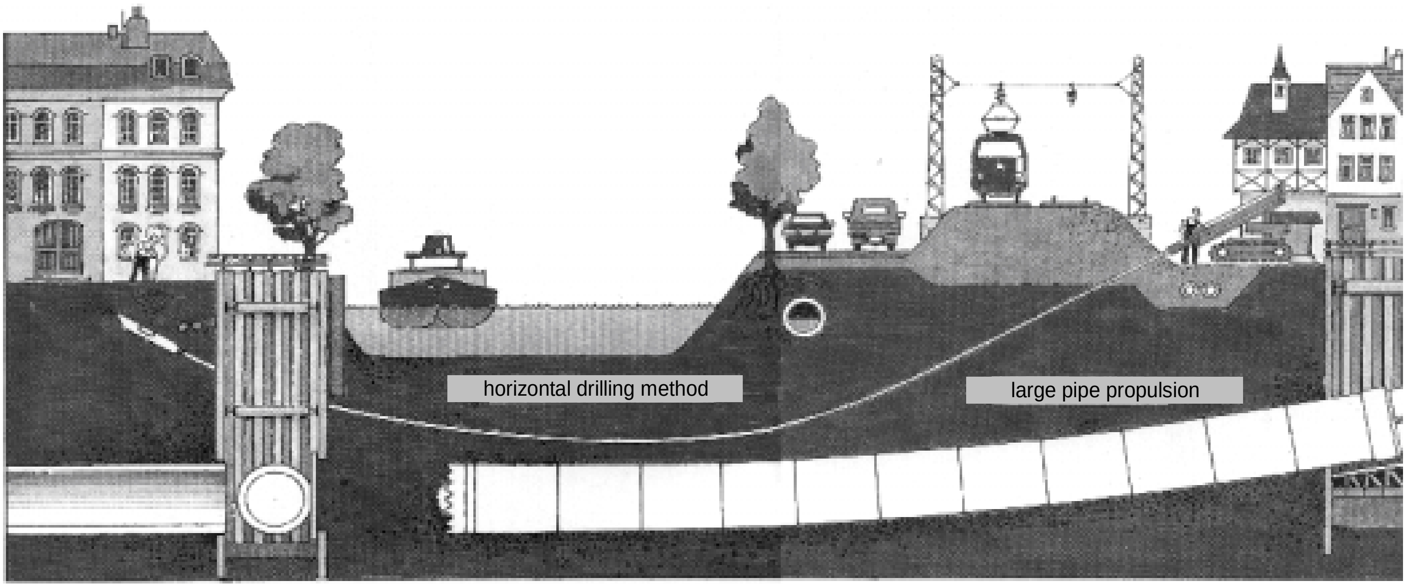
Each drilling method shows very different features in its application. In order to always be able to select the most favourable method, the builder must be clear about the most important properties. The principle criteria for differentiating between the processes are summarised in Table 4-2.

Table 4-2: Important criteria of drilling methods

Control	• controllable • not controllable
Installation of the pipe	• directly in the ground • in a protective pipe of steel or reinforced concrete
Installation	• installation during construction of drill hole • installation in completed drill hole
Working cycle in longitudinal direction	• continuous drilling method (e.g. horizontal hydraulic drilling) • fixed-cycle (e.g. hydraulic pipe propulsion)
Working cycle in radial direction	• construction of bore hole in 1st stage • pilot bore and then enlargement in further stages
Removal of earth	• no removal, displacement of soil • removal • hydraulic drilling (wet) • mechanical drilling (dry) • combination of hydraulic and mechanical

The fact, that there are considerable differences in the utilisation of the various drilling methods, is shown very clearly in Figure 4-2. The diagram shows the principles of hydraulic propulsion of large pipes with heavy equipment and the construction of a small pipeline with the hydraulic drilling method as alternative. The flexibility of the hydraulic drilling method is clear.

Figure 4-2: Diagram showing the principles of horizontal directional drilling and hydraulic pipe propulsion (Source: GSTT)



4.1 Requirements of drilling methods for district heating pipelines

The building sites for district heating pipelines have certain characteristics which the drilling technique should not affect. First it goes without saying that one pipe has to be laid for the supply and one for the return flow. This means that only a limited deviation in the positioning of the pipelines can be allowed. The uncontrolled drilling methods, whose accuracy of positioning is reduced with increasing length of the bore hole are therefore only useful for limited drilling distances. (The possibilities of constructing twin pipelines are discussed in Section 7.2.)

In the following considerations, it appears to be meaningful to divide district heating pipelines according to geometrical and functional qualities into the 4 categories listed in Table 4-3. House service pipelines are usually 8 to 15 m long and have the smallest diameter. They are generally constructed, as in the case for supply pipelines, with a coverage of from 0.6 to 1.0 m.

Table 4-3: Types of district heating pipelines

Type of Pipeline	Nominal diameter of the medium pipe DN	External diameter of the jacket pipe (mm)	Comments
House service pipelines	20 to 50…	90 to 140…	Length usually 8 to 15 m
Pipelines for subdistribution	50 to 150	125 to 280	Many branch pipelines Lengths often in the range 100 to 200 m
Pipelines for main and middle distribution	100 to 300	180 to 450	
Transport pipelines	200 to 800…	315 to 1000…	No branch pipelines, Lengths in the km-range

Laying nearer to the surface is more favourable for the installation of house service connections, which are often only constructed in the period after building the distribution network. It must be stated that in Table 4-3 the numbers given are reference numbers which may vary from case to case. For instance, in a very large district heating network, an average distribution pipeline can be larger than the transport pipeline in a smaller system.

District heating pipelines are usually installed at a shallow depth, i.e. with ca. 0.8 m coverage. This need not be adhered to when changing over to a closed construction, as the shallow installation is a result of the open construction used up to now. A very deep installation is however disadvantageous when future excavation is necessary to connect new customers. Furthermore, for district heating double pipes have to be installed for supply and return flows, and these have to be from 10 to 20 cm apart.

District heat building sites usually have to be organised under very narrow conditions along roads in towns. For this reason, advantageous small construction machines should be used, which also do not require large voluminous auxiliary equipment and if possible work without producing dust and noise.

Around the area of roads in towns where district heating pipelines are to be installed there is usually no undisturbed ground to be found. One comes across filled-in excavations, remains of foundations, etc.

District heating pipelines usually consist of a pipe length of steel, which has to be inserted in the bore hole in the microtunnelling process. The finished pipeline cannot be put together like a sewage duct from short pipe segments, as is most favourable for hydraulic pipe - propulsion. The working area required to install the prepared pipe length must be taken into account during the planning stages. In this connection, the advantages of flexible district heating pipelines are evident.

For this reason, this document concerns itself mainly with small pipelines of at least 80 mm diameter, which are installed in lengths of up to ca. 20 m (house service connections). In addition, pipelines of average to large diameters are considered, which are installed as distribution pipelines and as main pipelines. For these, pipeline tunnels with up to about 1.2 m diameter have to be constructed if supply and return flows each have a separate bore hole. On the other hand, they are of ca. 2.5 m, if they are conducted in a common protection pipe. Large tunnels, as constructed with diameters of from 2 to 5 metres, are not considered here as they represent a special building measure. They are usually constructed under special conditions and are therefore only considered in this report to make it complete, see Section 4.3.5.

For economic reasons there is a series of preferential diameters for the construction of pipeline tunnels, which are for the sectors sewage, drinking water, and gas [11]. This series of diameters should also be kept to for district heating pipelines:

DN	100	150	200	250	300
	400	500	600	800	
	1000	1200	1400	1600	
	1800				

In the following the individual drilling methods, suitable for the construction of district heating pipelines, will be described by means of outlining the principles of the methods. The drilling techniques are divided into the 2 categories: uncontrollable and controllable methods.

4.2 Uncontrollable drilling methods

In uncontrollable drilling methods, there is no possibility to change the direction of the propulsion during the drilling process. The drilling instrument is set in the launch trench with the homing device towards the target and sent off. The target is reached with a certain deviation from the set point if no particular problems occur. Difficulties can be caused by large stones in the ground or when the drilling line transverses along soils of two different densities. In this case the drill turns into the softer ground.
As uncontrollable drilling methods, the following 4 processes, summarized in Table 4-4 will be described:

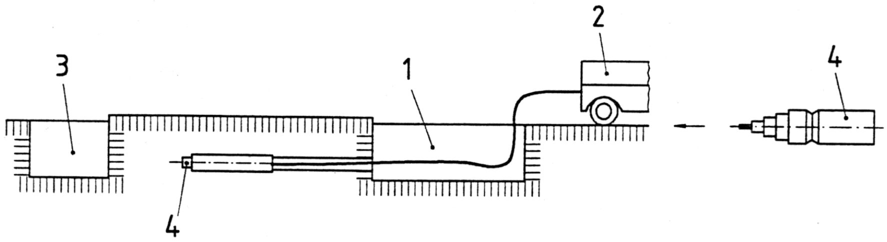
Table 4-4: Earth displacement methods

Earth displacement methods		
-	**Earth hammer (EVH)**	Displacement of the ground using ramming energy through a self-propulsion of an earth hammer; a simultaneous insertion of the product pipe is possible.
-	**Horizontal ram with closed pipe**	Displacement of the earth through the propulsion of a protective or product pipe rod which is closed at the front, with help of ramming energy.
Earth removal methods		
-	**Horizontal ram with open pipe**	Propulsion of a product pipe rod, open at the front, with help of ramming energy with either simultaneous or later excavation of the ground and its transport
-	**Horizontal hydraulic drill**	Propulsion of protective or product pipes with simultaneous excavation at the front using a drill head and continuous removal of the soil using a screw conveyor. The drive for the drill head and the screw conveyor are to be found in the launching trench.

4.2.1 Earth hammer (Earth rocket)

The earth hammer is a cylindrical pipe body, which is propelled through the ground by hammer blows. These are produced by a striking mechanism which is integrated in the pipe body and driven by compressed air, see the diagram of the principle in Figure 4-3 .

Fig. 4-3: *The working principle of an earth hammer and hammer head [1]*

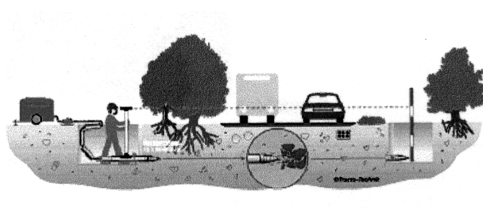


1 start shaft
2 compressor
3 target shaft
4 earth hammer

The earth hammer forces itself into the ground, by pushing earth particles to the side and possibly crushing them to small pieces. The direction of motion of the equipment can be switched to forwards or backwards. The earth hammer is simple and robust and is used very frequently.

For drilling, the drill is set in position in a launching shaft and aligned with a bearing finder, see Figure 4-4. The launching shaft must be somewhat longer than the earth hammer so that the drill can be operated (ca. 2 m).

Fig. 4-4: Alignment of the earth hammer, according to [3]



There are several possibilities for installing the pipe. Either a protective pipe is installed first of all or the district heat pipe is immediately pulled through. In addition, the pipe to be installed can be pulled in with the propulsion of the earth hammer whereby it is coupled to the earth rocket. However, on the other hand, if the ground is sufficiently stable, the bore hole is completed first and finally the pipe is pushed or pulled through. When constructing the bore hole, if the district heat pipe is not immediately inserted, it must be taken into account that the diameter of the hole during construction can shrink by 10-15 %.

In practice, variations to the process described above have developed, for instance, expansion: in the first phase a pilot bore hole is drilled and this is opened up in a second phase. In Figure 4-5, in addition to the pneumatic propulsion of the earth hammer, two supporting measures are shown. The hammer is pulled out of the target shaft with a cable line and the pipe to be installed can possibly be pushed with the help of a second cable line as shown in the figure. In this way, using an expansion adapter as in Figure 4-6, an earth rocket can also be used for the construction of larger diameters.

Fig. 4-5: Stepwise drilling with an earth displacement hammer
Pilot bore
Expansion

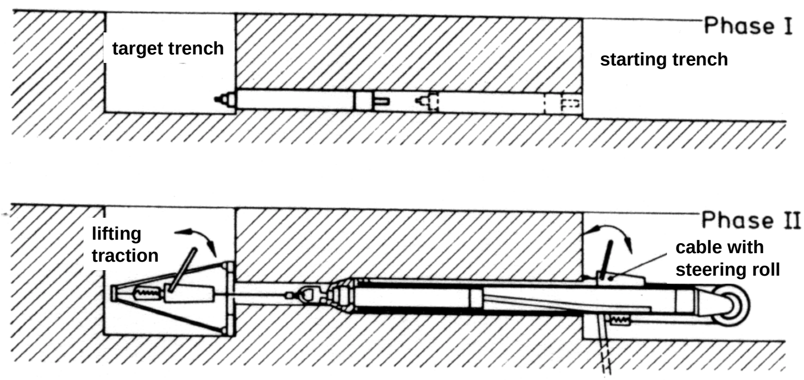
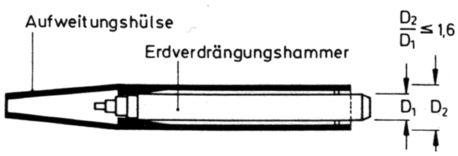
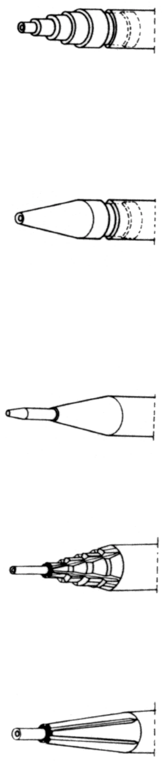


Fig. 4-6: Earth hammer with expansion adapter



Earth displacement hammers usually have a spring-loaded sliding head. Different drill heads are used according to the type of ground. Figure 4-7 shows various types and explains for which soil types they are suitable.

Fig. 4-7: Heads for earth displacement hammers according to [3]



1. adjustable stepped head

for sand and gravel soil with low jacket friction but high point resistance

directional stability: good even in inhomogeneous soil

speed: low

2. adjustable conical head

for homogeneous fine-grain types of soil without rubble stones

directional stability: good in homogeneous soil

speed: good

3. conical head with chisel joint

for all types of soil up light rocks

directional stability: only good in homogeneous soil

speed: good

4. combination head

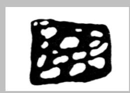
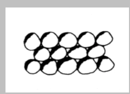
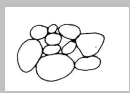
- accurate
- the front chisel breaks up and splits obstacles
- faster than a graded head

5. combination conical head

- more accurate than a conical head
- the front chisel breaks up and splits obstacles
- very fast

The earth hammer can be used extremely well in mixed pebbly soil without particles more than 60 mm and with only a small share of binding materials. In the classification according to DIN 18300 (see Appendix 1) manufacturers offer their equipment for the ground classifications 1 and 3 to 5 (and possibly 6). Earth rockets are generally not usable in ground water. An overview of which soils can be displaced and are therefore suitable for the application of earth rockets is given in Table 4-5.

Table 4-5: The displacement properties of various soils [3]

	mixed-grain soil without ground water	loose deposit	easily displaced
	mixed-grain soil without ground water	dense deposit	difficult to displace
	water-saturated mixed-grain soil	the finer the grain particles the lower the perviousness	not displaceable without drainage
	single grain soil	most dense deposit	only displaceable when individual grains have been broken down
	sharp grains		difficult to displace
	round grains		displaceable

Earth rockets have proved themselves in practice for hole diameters up to 20 cm and lengths of up to 25 m. The propulsion distances that can be achieved with earth displacement hammers is max. 35 m since the drill is not controllable. Manufacturers consider the limit for application to be 50 m. Problems in keeping to the correct direction can be caused by sloping strata or erratic blocks.

8 to 12-times the drill diameter is required at least coverage for work with earth rockets so that thrusts on the surface are avoided. The low value is valid for multi-step heads and the higher value for slim hammer heads.
Under solid road surfaces the coverage should not be chosen too low. This separation should be kept in relation to all obstacles.

4.2.2 Horizontal ram

For the horizontal ram, a pipe is pushed into the ground by a ram, which stays in the launching shaft. Such a ram has the same construction as an earth hammer. A horizontal ram is an earth hammer with an adapter for connection to the pipe. Figure 4-8 shows schematically the way a horizontal ram works.
In the horizontal ram a protective steel pipe is installed and this takes up the later district heating pipeline. If the pipe is closed at the front end with a cone body, the process works according to the principle of earth displacement. Alternatively, the pipe can be left open at the front end and works by removing the earth, whereby considerably higher pipe diameters can be driven than by simple earth displacement, maximum ca. 1500 mm diameter.

For the horizontal ram with closed pipe the above descriptions on the earth hammer are valid. The horizontal ram requires a larger launching shaft than the earth rocket. However, it offers the advantage that it can be used in a wide spectrum of soil types. With the horizontal ram pipe propulsion is possible even in filled-in ground and drifting sand or in ground water. The speed of propulsion is usually between 1 and 10 m/h.

If open pipes are rammed, then earth must be removed from the pipe. There are processes which remove the soil at intervals and others where removal occurs continuously.

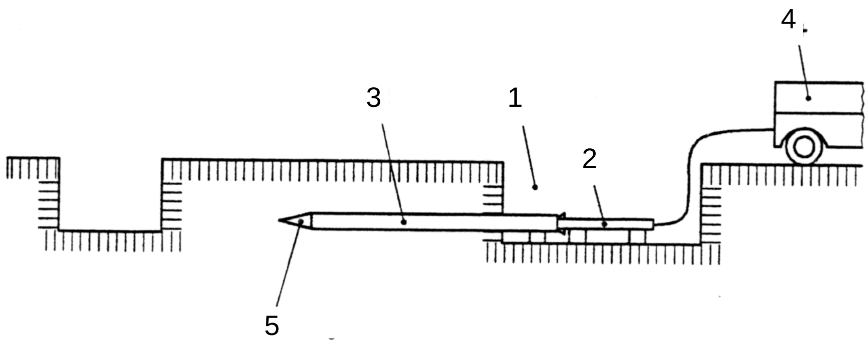


Fig. 4-8: The way a horizontal ram works [1]

1 start shaft
2 horizontal ram
3 propulsion pipe with with closed front pipe-end
4 compressor
5 detail: closed front pipe-end

Another variant of the horizontal ram works with a pilot drilling. First of all a smaller bore hole is drilled, for instance with an earth rocket, then this hole is expanded with a ram in the 2nd phase. Figure 4-9 shows a case where the ram is supported by a cable line. In this diagram, the earth is removed by being transported hydraulically out of the pipe.

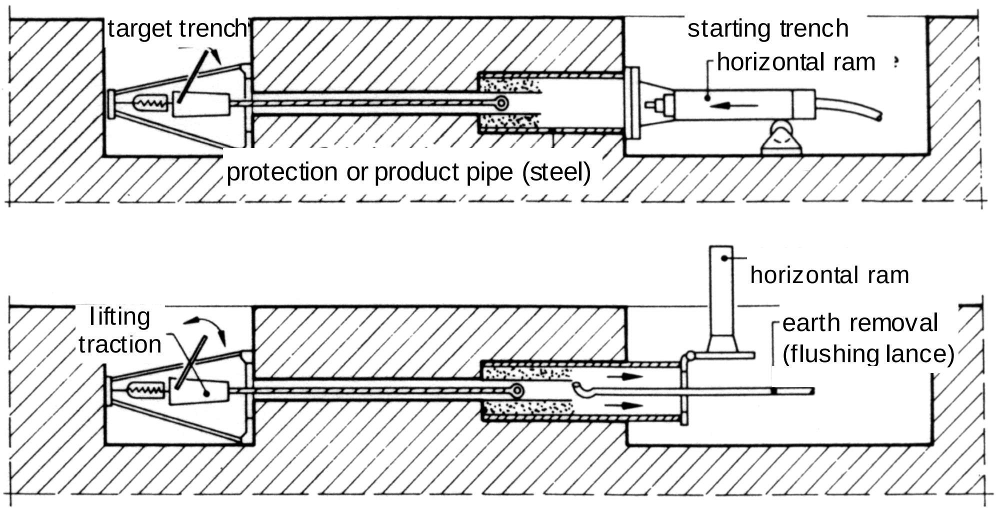
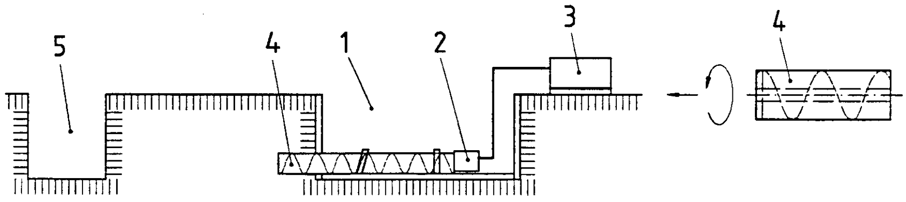


Fig. 4-9: Horizontal ram with earth removal, propulsion supported by traction

4.2.3 Uncontrollable hydraulic drilling

In hydraulic drilling an open steel pipe is forced into the ground by a hydraulic pressing station. The complete pipe is assembled from individual lengths. The earth at the front is continuously cut through with a rotating drill head and with the aid of a screw conveyor transported to the launching shaft. The screw conveyer and the hydraulic propulsion work independently from one another. The reaction forces of the press apparatus must be introduced into the ground in the launching shaft. Figure 4-10 shows schematically the way the hydraulic drill works.

Fig. 4-10: Hydraulic drilling method [1]



1 start shaft
2 press and drilling aggregate
3 hydraulic pump
4 drill head and screw conveyer
5 target shaft

Before propulsion begins, the hydraulic drill must be carefully aligned to achieve a sufficiently accurate orientation for the bore hole. The drilling system is positioned in the trench, the auxiliary equipment for the hydraulics is positioned outside the trench.

The type of drill head used depends on the ground to be cut through. Drill heads range from those with large flat blades to cut through sandy soils to chisel heads for working rocks. For drilling in solid ground there are drill heads which simultaneously rough drill and cut the propulsion pipe free by swinging out knife edges.

Uncontrolled hydraulic drillings are carried out in the diameter range from 150 to 1500 mm and up to a length of 80 m. A propulsion speed of 1 to 12 m/h is achieved.

The hydraulic drilling method is suitable for all soil types up to light rocks.

4.3 Controllable methods

Today the horizontal hydraulic drilling method for the construction of supply pipelines is the leading drilling method. Although it is a new development, there is a wide spectrum of manufacturers and service providers. The particular advantages of horizontal hydraulic drilling are the high mechanisation of the work, the continuous way of working and the special qualities of the flushing fluid. This serves not only the hydraulic transport of the excavated earth but also the support and lining of the bore hole.

In addition there are also controlled dry drilling methods with purely mechanical cutting through the earth and the building of pipeline tunnels according to the pipe propulsion process. For up to about 1200 mm inner diameter, pipe propulsion is carried out unmanned. The process is then automatic and the excavated earth is hydraulically transported. For diameters greater than ca. 1.2 m the bore holes can be negotiable.

4.3.1 Horizontal hydraulic drilling

The horizontal hydraulic drilling method, often called directional or horizontal drilling, is the optimum drilling method for pipelines with diameters up to DN 600 in soils in the classifications 3-5 (see Appendix 1). Horizontal hydraulic drillings are also possible in difficult soils. A drilling system consisting of a drill and the auxiliary supply equipment are always required. The bore hole is constructed using a controllable rinsing lance whereby a washing fluid of water and bentonite is used for the hydromechanical drilling and the transport of the earth. First a pilot bore hole of ca. 6 cm diameter is constructed. In following stages this will be enlarged step-by-step until the bore hole has the necessary diameter.

Figure 4-11 shows the principle of the horizontal hydraulic drilling method. In the first step, the drill aggregate with the magazine for the drilling rod drills a pilot bore hole. Modern drills change the drill rod automatically during the work. In the 2nd step working in the opposite direction, the pilot bore hole is opened out to the necessary size and at the same time the pipe is pulled through.

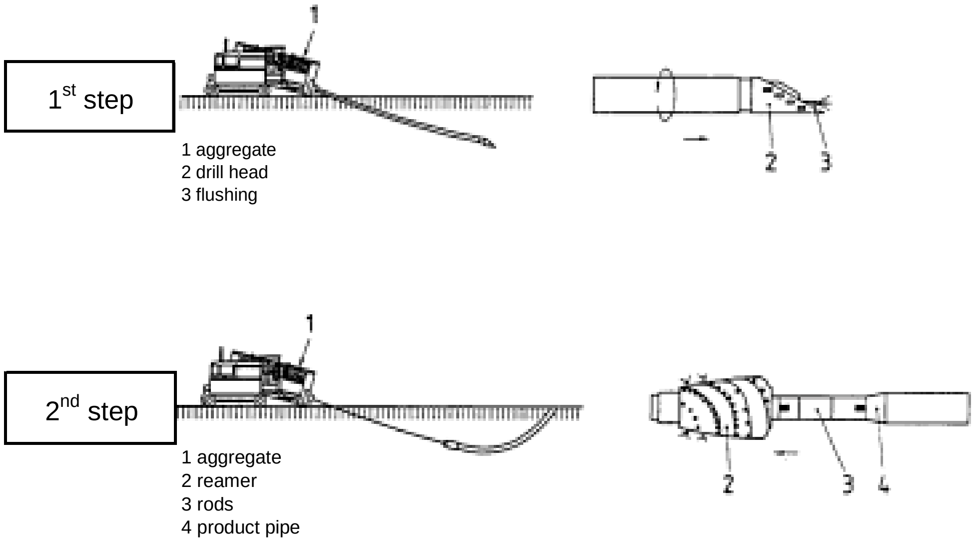


Fig. 4-11: Principle of horizontal hydraulic drillings

Work Process

The equipment and the building site for horizontal hydraulic drilling can be seen in Figure 4-12. In the upper diagram the construction of the pilot bore hole is shown. The actual drill is placed on a carriage mounted on a vehicle. The drill is directed into the ground at an angle of under 15°. Drilling is carried out with thin, sharp, water cutting (bentonite) jets which come out of nozzles in the drill head.

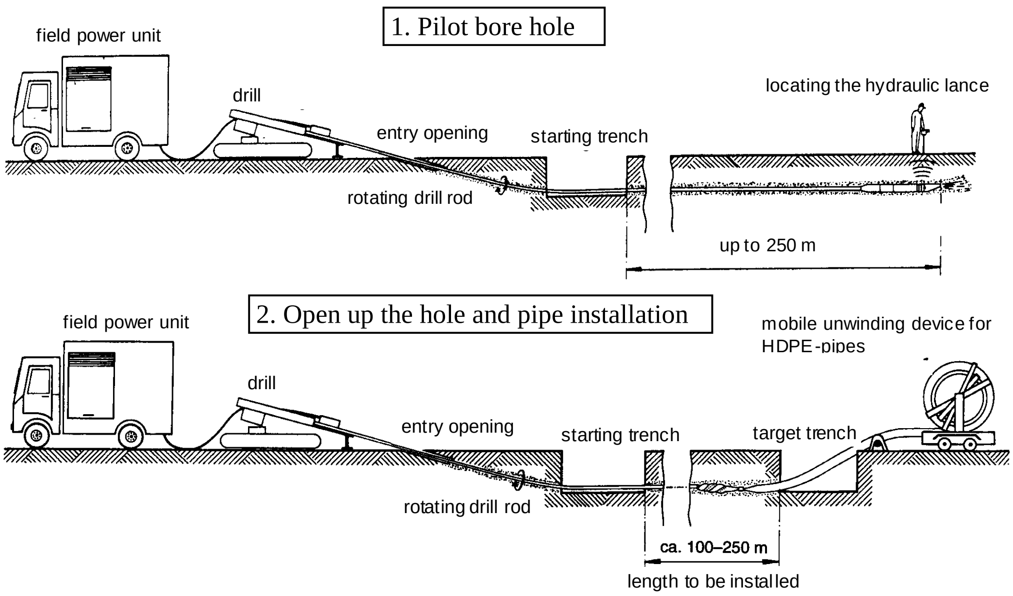
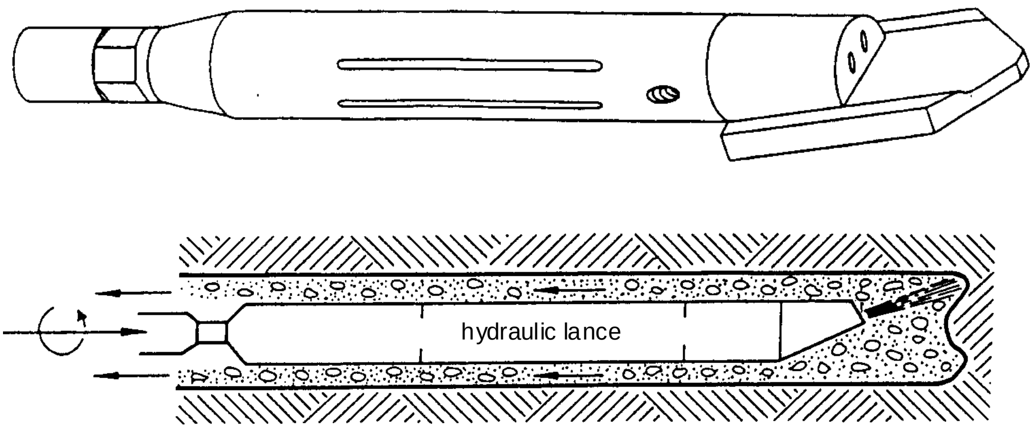


Fig. 4-12: Working process for horizontal hydraulic drilling [13]

The drill head, drilling lance, has an eccentric system of nozzles and a facet or sloping deflecting plate, see Figure 4-13. Different drill heads are used depending on the type of soil. For this reason it is only possible to travel straight ahead if the head is rotated evenly. A bore hole is produced in front of and around the hydraulic lance and this is somewhat larger than the diameter of the drill head, see Figure 4-13 below. Uneven rotation of the drill head causes curves to be driven; in this way the drill head is controllable.

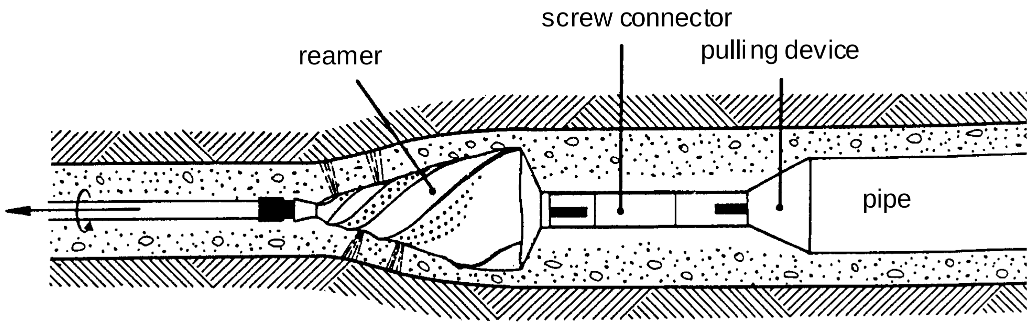
Fig. 4-13: Drill head (hydraulic lance) [9,13]



The horizontal hydraulic drilling method is carried out in difficult soils with drilling heads where hydraulic cutting is supported mechanically. In this case the rotating drill head is fitted with spikes or teeth and is additionally propelled by pressing and sometimes by hammering.

The opening out of the pilot bore hole to the size required for pipe laying is undertaken in one or more steps, see Figure 4-14. The final size of the drill hole is several centimetres larger than the pipe diameter. During the final opening up of the hole the pipeline is attached to the opening up head. It is then pulled from the target shaft into the launching trench.

Fig. 4-14: The opening-out process



The particular advantage of horizontal hydraulic drilling lies in the simple controllability of the drill head. Obstacles can be driven around without great difficulty, see Figure 4-15. The possible radii of curvature of the pipe axis is 30 m for pipes of 20 cm diameter and 70 m for pipes of 60 cm diameter. A precondition for the control is the exact location of the drill head. The simple location process implied in Figure 4-12 (top) uses a transmitter fitted in the drill head. Through patrolling the path of the pipeline, the drill head is surveyed so that the drill progress can be controlled. Such equipment can operate up to a depth of 8 m. Larger drills are fitted with an electronic navigation system in the drill head. The signals are transmitted by cable in the drilling rods and continuously shown at the control station. This equipment works for any depths. The accuracy of measurement is given as 2 % of the depth (in all directions) (ca. ± 5 cm).

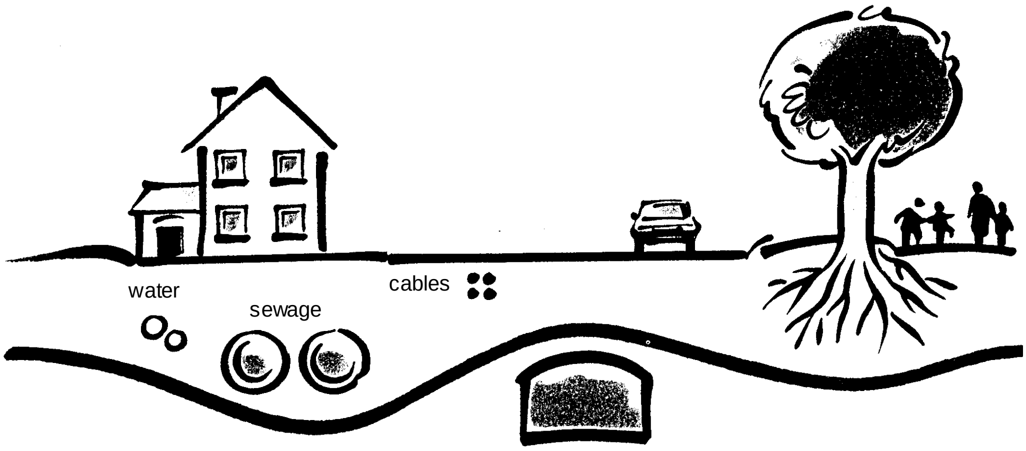


Fig. 4-15: Possible path of a pipeline for horizontal hydraulic drilling [13]

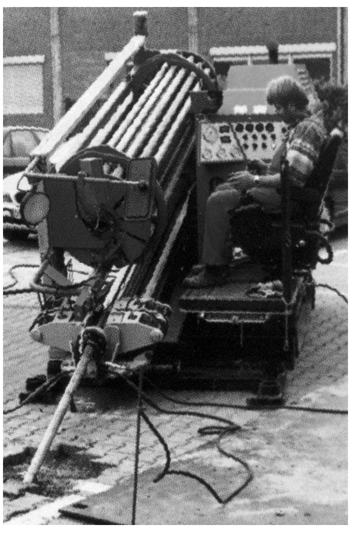


Fig. 4-16: Small horizontal hydraulic drill

The equipment necessary on the building site is strongly dependent on the pipe dimensions. Figure 4-16 shows a self-driving small drill, which can be used on roads in towns and in built-up areas. See Figure 4-17 for large drills.

Fig. 4-17: Large horizontal hydraulic drill

The flushing fluid (Bentonite)

The flushing fluid is a mixture of water and bentonite, to which chemicals may also be added, see Section 5.3. Depending on the type of soil there are different compositions of the flushing fluid. Bentonite is made in a special mixing unit. It serves as fluid for drilling and by flowing into the trench it transports the excavated soil out of the bore hole. At the same time, bentonite supports the grain structure, so that the bore hole does not cave in when drilling in loose soils. On the wall of the bore hole a soft slidable layer of several millimetres is formed. This is a good lubricant for the drill rod. Moreover, it protects the surface of the pipe when it is inserted later. The resistance and hence the forces required to pull in the pipe in bentonite are low.

Finally, the pipe lies in a mixture of earth and bentonite. Visually this can no longer be seen on an excavated pipeline, see Figure 4-18 (top). Exact investigations on pipelines laid according to the HDD-method [25], show the bedding situation schematically reproduced in Figure 4-18. The pipe lies in a mixture of drill-suspension and earth. As the pipe swims in during installation, it comes to rest high in the bore hole . Round the bore channel the earth is soaked with the bentonite suspension. This area is marked “transition area“ in the Figure.

During installation of the pipe, the surrounding mixture of drill-fluid and earth has a large water content. Afterwards the water content becomes the same as the surrounding area, whereby shrinking occurs. In the investigation [25] fissure-like cavities were found over the top of the pipe. However, shrinking is so small that one expects that even under railway tracks hydraulic drilling can be carried out without problems.

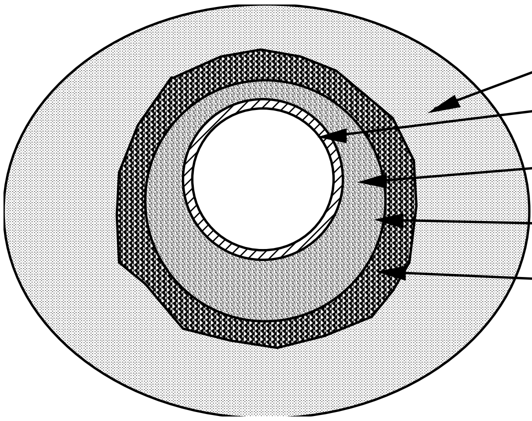


Fig. 4-18: Bedding of the pipeline in hydraulic drilling
top: excavated gas pipe,
bottom: schematic diagram [25]

Horizontal hydraulic drilling with bentonite is a most protective process for the pipeline. Loose rocks are rearranged and existing sharp edges are bedded in the bentonite suspension. The volume of voids is filled and the grain structure reinforced, so that the pipe surface is protected as it is forced into place.

Excessive bentonite must be removed from the site; it cannot remain in the pipe shaft. Large quantities of bentonite are recycled; at large building sites bentonite is circulated. Bentonite is considered environmentally benign.

Area of application

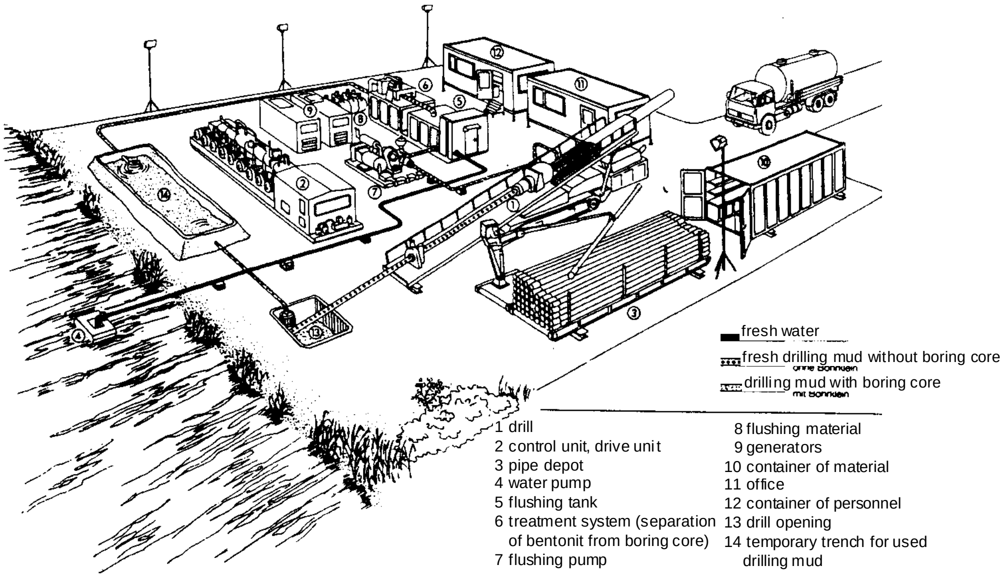
Horizontal hydraulic drilling can be used for drilling diameters up to 400 mm and for distances up to 250 m. It can be applied in soils in the classifications 4 to 5, which do not compose of any rocks or debris. The properties of the ground must be explored beforehand. Horizontal hydraulic drilling does not work in coarse gravel soil, highly pervious to water.

4.3.2 Horizontal hydraulic drilling with large drilling equipment (HDD Horizontal Directional Drilling)

Using HDD bore holes of up to 1.5 m diameter and propulsion distances of up to 1500 m can be constructed. The HDD-method is suitable for all types of soil.

An HDD-building site requires sophisticated equipment and a large area. Without going into details of this, Figure 4-19 should be sufficient to demonstrate the complexity of the procedure. The HDD-process is treated in more detail in [9].

Fig. 4-19: HDD-building site, launching side

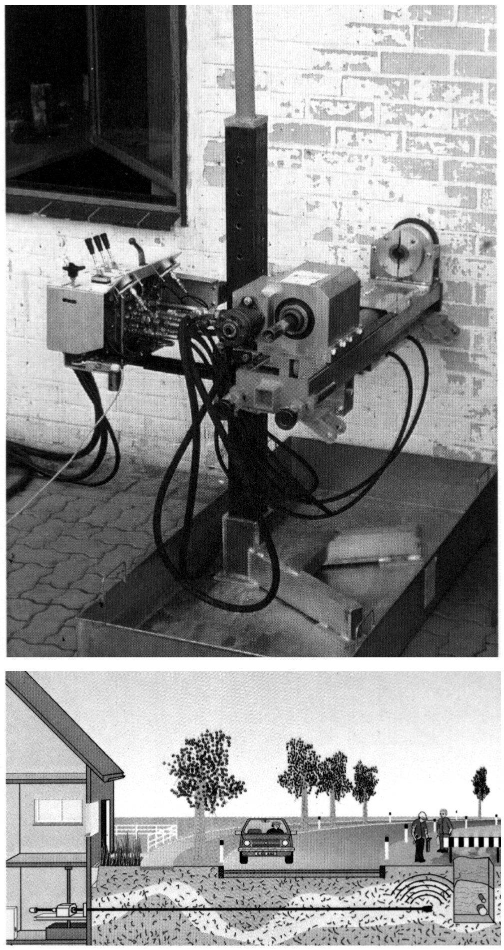


4.3.3 New microtunnelling methods

Effective cost reductions to improve the economics of district heat supply are not to be expected so much from large technical developments as from savings from frequent occurring situations, i.e. in the area of small pipe diameters and for house service connections. For this reason, horizontal hydraulic drilling is particularly interesting, if it is adapted for small pipelines. In the meantime light, transportable horizontal hydraulic drills are available and these can efficiently construct bore holes for house service connections and small pipelines. The new development (by DMT) described in the following, envisages the setting up of microtunnelling equipment even in the cellars of houses so that, from there, first the core drill and then the bore hole for the house service connection can be made.

The way the DMT-drill works is described here using the example of a drilling from a cellar. If the drill is not set up in a cellar, an additional shaft must be made at the house wall. Figure 4-20 shows the drill and method of working.

Fig. 4-20: Horizontal hydraulic drilling from a cellar using a small unit



The hydraulic drill is installed in the cellar and guyed with supports. The drive aggregate for the hydraulic motor is set up outside the building and connected b means of tubes. First of all, the core drill is made using a crown drill; then the ground is bored through or opened out. Flushing water which flows into the building is collected and pumped away. The advance of the drill head is continuously monitored.

The pipe is pulled in from the target shaft. The passage through the wall is made from the building side.

The application of the DMT-microtunneller outside the building can be seen in Figure 4-21. As opposed to other horizontal hydraulic drilling methods it is installed in the trench. It only requires a trench length of 1.6 m, the same size as for an earth hammer.
DMT-hydraulic drilling can be used for drillings up to a diameter of max. 225 mm. The longest laying length is 40 m. It is suitable for all types of soil, including rocks.

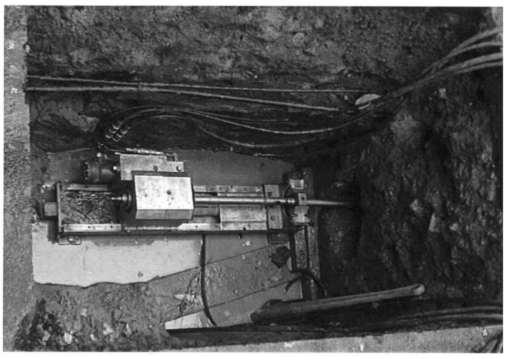
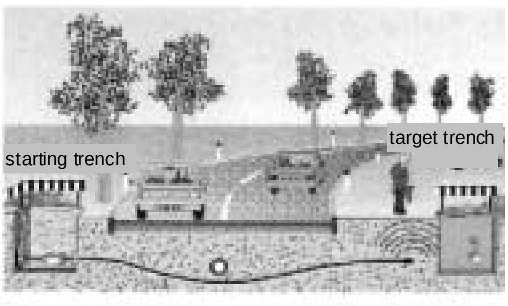


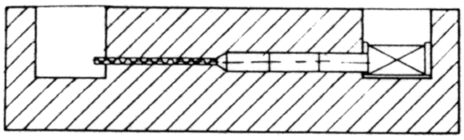
Fig. 4-21: Horizontal hydraulic drilling with microtunneling device on an open space



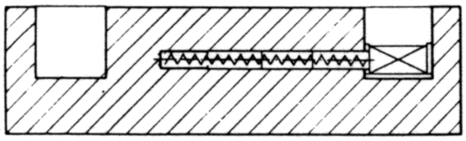
4.3.4 Pipe propulsion process

Another group of unmanned drilling methods covers the various types of pipe propulsion methods. According to [3], 3 groups can be identified:

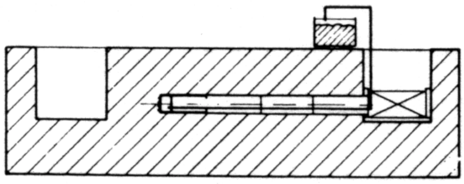
a) pilot pipe propulsion



b) pressurized pipe propulsion



c) shield pipe propulsion



a) pilot pipe propulsion

For pilot pipe propulsion a pilot bore hole is first constructed with a controlled drill whereby a pilot pipe rod is pulled into position. The control of the pilot drill is obtained by twisting the pilot pipe rod from the launching shaft. In a later stage, the elements of the pilot pipe rod are pushed or pulled out pipe-by-pipe, the bore hole opened out and the protective pipe or product pipe inserted in place.

The pilot pipe propulsion can be used for short pipe segments of up to 200 mm diameter and for lengths from 30 to max. 100 m.

b) pressurized pipe propulsion

While a protective pipe is being pressed hydraulically into the ground for a later insertion of the district heat pipeline, the earth is continuously being cut through with a drill head at the front. Changes in direction are possible by means of hydraulic adjustment of the steering head. The drill is driven from the launching shaft and a screw conveyer transports the excavated soil out of the bore hole. An example is shown in Figure 4-23.

This type of pipe propulsion is used for diameters of up to 1300 mm and over distances up to 100 m.

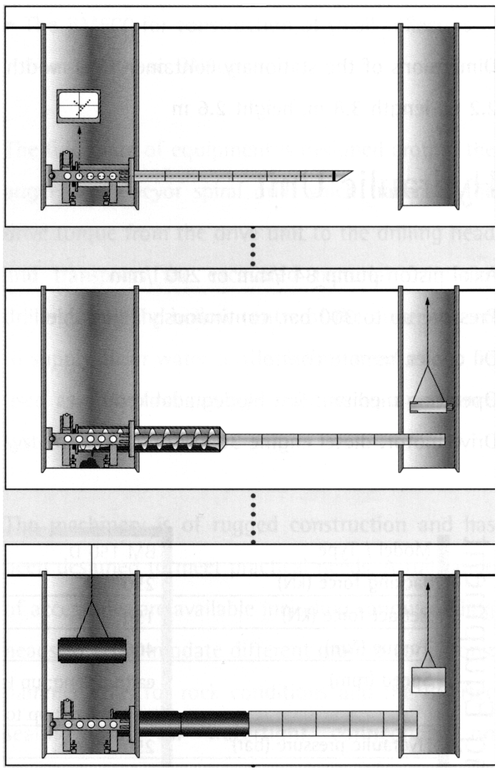


Fig. 4-22: Pilot pipe propulsion method [22]

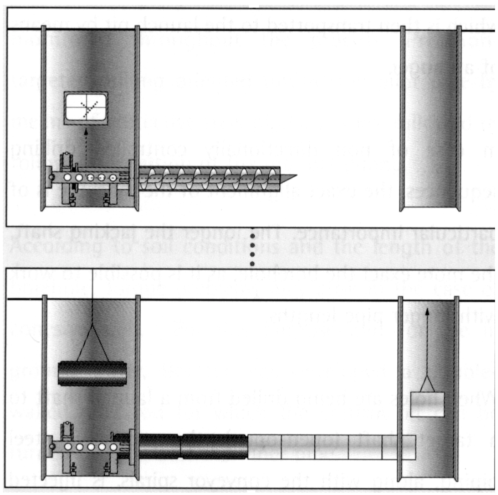


Fig. 4-23: Pressurized pipe propulsion [22]

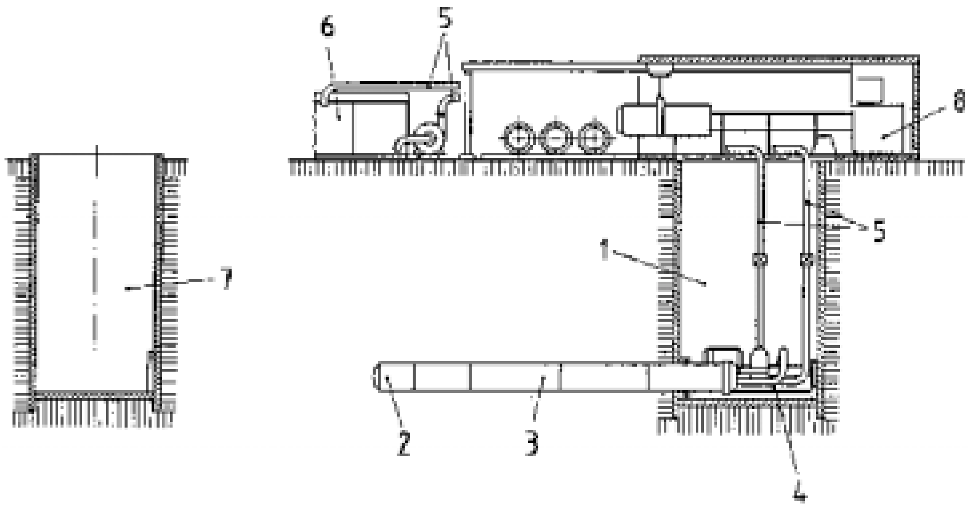
c) shield pipe propulsion

In the case of shield pipe propulsion, a protective pipe is pressed into the ground with hydraulic presses, whereby at the same time the soil is excavated at the front end. The bore hole is measured with a laser and the drill head is hydraulically controlled by angular variation.

The drive of the drill head is to be found in the shield. The excavated soil is continuously transported to the launching shaft, usually hydraulically, see Figure 4-24, or even mechanically, Figure 4-23.

The unmanned shield pipe propulsion method is used for protection pipes up to 1800 mm diameter and over distances of up to 250 m.

Fig. 4-24: Shield pipe propulsion with hydraulic transportation of soil [1]



1 Start shaft	5 charging and discharging pipes
2 drill head	6 settler
3 propulsion pipe	7 target shaft
4 press	8 aggregate

4.3.5 Manned pipe propulsion

Pipeline tunnels, which are built using manned pipe propulsion, are always special building measures requiring a great deal of effort and which have to fulfil particular requirements. Often there are difficult railway tracks or roads to cross, rivers and waterways to get by or requirements of the landscape and environmental protection to fulfil. Since these building measures generally do not compete with open construction, they are not seen as alternatives to conventional pipe building but are only mentioned in this report in order to be complete. Manned pipe propulsion is carried out with pipes of at least 1200 mm inner diameter and up to diameters of ca. 5 m. Figure 4-25 shows pipe propulsion for crossing a district heat transport pipeline with a railway line.

The soil is usually cut through by machines but also with fluid-jet-cutting and mechanically or hydraulically transported away.

Using a hydraulically controlled shield, the pipes can be driven in curves. For long presses in which the pre-press forces at the starting point would be too high, interim pressing stations are installed. These types of large tunnels are often to be found in the ground water area. If a pressure resistance has to be established with air, it can often be so arranged that the excavation at the front works by remote control. The operators then work at normal pressure and the front only needs to be inspected by means of locks in special cases, see Figure 4-26.

Figure 4-26 shows a large construction, the district heat pipeline tunnel crossing the Kieler Förde. It has an inner diameter of 4.1 m and a length of 1368 m.

Fig. 4-25: Pipe propulsion for district heat transport pipeline (Line Mannheim-Heidelberg)

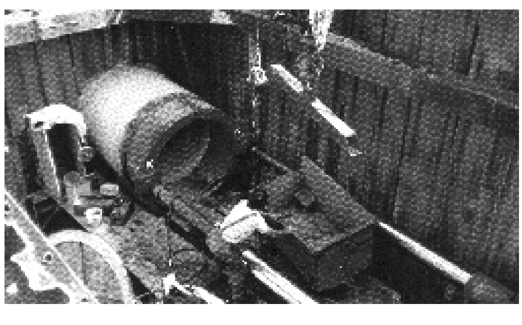
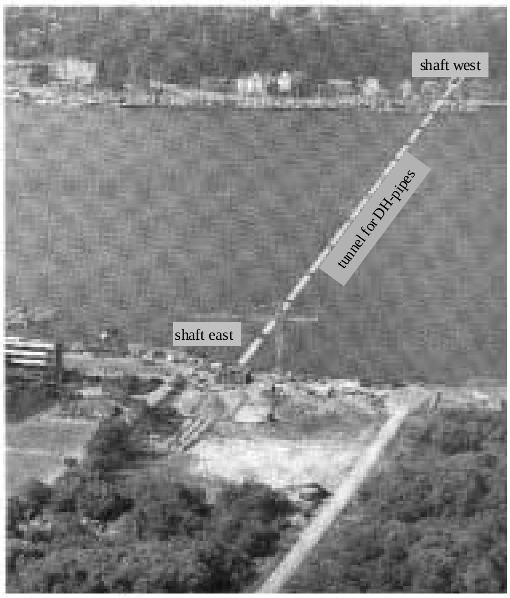
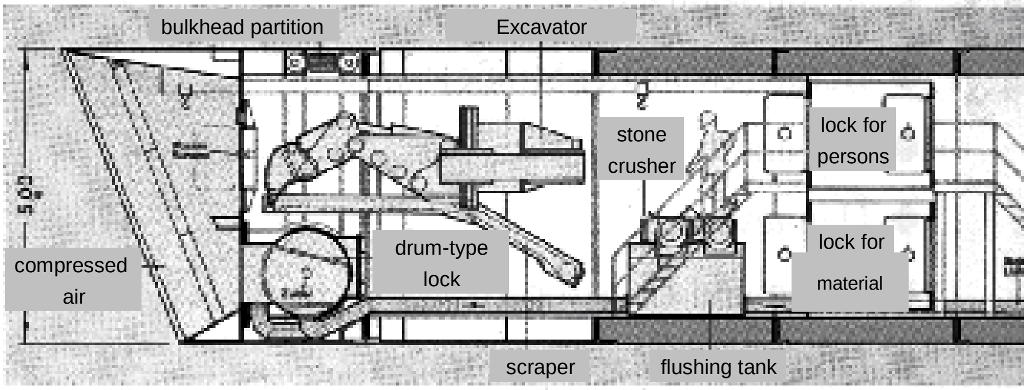


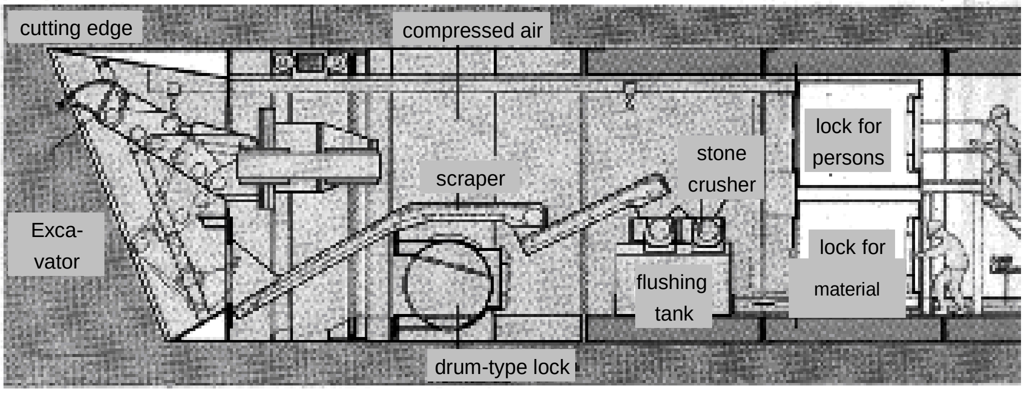
Fig. 4-26: District heat tunnel at the Kieler Förde



propulsion in non-cohesive soil



propulsion in cohesive soil



4.4 Overview: Drilling methods for district heating pipelines

The working areas of drilling methods with regards to diameter and length has been given in the sections 4.2 and 4.3. They are summarised again in Table 4-6. The Table contains additional information on space requirements, handiness of the equipment and the working speed.

Furthermore, 2 features are important for assessing construction methods for district heating pipelines:

1. District heating pipelines consist of long steel pipe rods, which have to be inserted in the bore hole as a complete length. The pipeline cannot be put together from short segments as in the case of sewage pipes. Therefore, drilling methods, which press the pipe in sections into the ground, can only be used for installing protection pipes into which the district heat pipeline has to be inserted later.

2. District heating pipelines are very much at risk from external damage. The steel pipelines are surrounded by a relatively soft thermal insulation of PUR-foam, which is protected against damp from the soil by a plastic jacket. These envelopes must be treated carefully and cannot bear any high forces or knocks, such as those which occur in pressing or ramming.

The connecting sleeves of the preinsulated pipes are particularly sensitive. If necessary, they will require special protection.

From the descriptions of drilling methods in the previous sections, it is clear that the processes stress the pipe to various extents during the insertion process. Pressing, ramming and the pipe propulsion method stress the pipe so much that in building district heating pipelines the sensitive district heat line cannot be directly installed. A protection pipe of steel or concrete in which the district heat pipeline is later inserted has to be installed first.

The situation is more favourable in the case of the earth hammer and horizontal hydraulic drilling. Using the earth hammer a bore hole with a certain oversize is constructed with the tool and the district heat pipeline can be pulled through without high forces of resistance. Since the bore hole is stable throughout the building period, only small normal forces from its own weight and low shear stresses through the axial shifting on the bedding occur as stresses to the pipe surface.

The situation in the case of the horizontal hydraulic drilling is even more favourable since the bore hole is filled with a bentonite suspension. Bentonite makes a stable bore hole which has an oversize of several centimetres. In addition, the lining of the bore hole with a pasty mass of bentonite produces a separation between the pipe wall and the wall of the bore hole. It results in an even load distribution over the pipe surface and, as a result of the anti-friction properties of bentonite, low feed-in forces and so less stress during installation of the pipe. Bentonite also fills the existing cavities so that the danger of settlement is less.

Table 4-6: The most important properties of drilling methods for building district heating pipelines [3, 11];
values in brackets: individual extreme values according to the manufacturer

If one also considers the working rhythm of the pipe construction processes, whereby the horizontal hydraulic drilling as well as drilling with earth displacement hammers are continuous processes, while the pipe propulsion method is discontinuous, then one can make the following prognosis for the economic prospects of trenchless laying of district heating pipelines:

Method		controllable	max. diameter [mm]	max. length [m]	Least coverage	Soil classification according to DIN 18300	Working area with relation to groundwater level	Size of the Trench for DN 100 Launch [m]	Target [m]	Form of the drill Length [m]; Weight [kg]	Speed m/h
Earth hammer (Earth rocket)		n	200	25 (50)	10 x Da	1,3 to 5 (6)	above (and below)	Da = 100 2.2 x 0.5	 1.7m x 0.5	Cylindrical drill for DN 100 length 1.6m; 100 kg	5 - 20 (Sand) and more
Horizontal ram	with earth displacement	n	150	20	12 x Da	1,3 to 5	above	for DN 100 ca. 8 x 1	 ca. 8 x 1	Similar to No. 1 for DN 100 L = 1.5 m; 100 kg	1 - 10
	with earth removal	n	1600	80	2 x Da min. 1.0 m	1 to 4		for DN 500 ca. 10 x 1	 ca. 10 x 1	for DN 500 L = 2.5 m; 1200 kg	5 - 20
Pipe pressing	uncontrolled	n	1600	80	2 x Da min. 0.8 m	Not uniform	above	2.3 Ø	1.2 Ø	Drill press unit with separate hydraulic system; Lifting unit necessary	1 - 12
	controlled	y	1300	100	1 (0.5)	2 to 4 (to 7)	above (and below)	2 Ø	1.2 Ø		
Horizontal hydraulic drilling	Hydraulic drilling	y	400	250	0.8	4 5 6	above and below	1.6 x 1	1.6 x 1	Carriage on vehicle and aggregate	2
	Microtunnelling	y	225	40	0.8	all	above and below			Drill motor and carriage; est. 110 kg	
	HDD Horizontal Directional Drilling	y	up to 1500	1500	0.8	all	above and below			Carriage on vehicle and aggregate	
Pipe propulsion method	unmanned	y	from 200 to 1800	250		all	above and below			Heavy equipment with aggregate	1-3
	manned	y	1200 to 5000	2000		all					

Horizontal hydraulic drilling methods have the best chances of becoming successful in the competition for economic feasibility compared with building in open trenches. Short pipeline sections for house service connections and similar small pipelines up to 35 m length can also be advantageously built using earth displacement hammers.

Unfavourable prospects are foreseen for the other methods namely ramming, pressing and shield propulsion in the large-scale business of longitudinal laying. They are believed to be building techniques for special constructions such as for laying protective pipes at crossings with railway lines and main roads. They will become competitive when underground engineering companies have the necessary equipment at their disposal and undertake such drillings more frequently.

This estimation is confirmed in the Swedish report [19]. In this document a comparison between the techniques and the costs of trenchless building was undertaken. For main pipelines the HDD-method was shown to be advantageous and for house service connections the use of earth rockets. The cost comparison is given in Section 9.2.

The advantages and disadvantages of the drilling methods are summarised in Table 4-7. There are only 2 problems which still have to be dealt with in more detail, namely the subjects bentonite and pressing forces.

Bentonite is used as flushing fluid in horizontal hydraulic drilling and in pipe propulsion as lubricant or for cutting and transport.

Bentonite is a suspension of expanded clay minerals adapted to the properties of the soil. The use of bentonite causes costs, on the one hand as a result of its use, and, on the other hand, from costs for its disposal. Excess quantities of bentonite must be disposed of as it is not suitable as road material. It does not create any problems in the area of the pipeline bed where it fills the space between the pipeline and the bore hole wall. Here it is in fact advantageous as it helps to prevent settlement.

In the case of drilling methods where the pipes are hydraulically pushed into the soil, the reaction forces of pressing must be directed into the ground. It should be taken into account that, when applicable, the back wall of the launching shaft must not only be able to support the load required but that it must not be possible for the reactions to damage neighbouring pipelines or buildings.

Table 4-7: Advantages and disadvantages of drilling methods

Method	Advantages	Disadvantages
Earth hammer (Earth rocket)	installation of the pipeline without protective pipe possible light device for wide soil spectrum small trenches immediate drawing-in of pipe	only for max. 200 mm diameter not in groundwater only short lengths up to ca. 35 m uncontrollable, strong deviations in direction in inhomogeneous soil possible
Horizontal ram	light device (as earth rocket) suitable for unstable soil suitable in ground water with open pipe (earth removal) up to 1500 mm Ø and for lower coverage than for earth rockets	for district heating pipelines only with protective pipe (steel) large launching trench necessary only short lengths up to ca. 20 to 50 m uncontrollable, strong deviations in direction in inhomogeneous soil possible
Pressing drill	no high coverage necessary	for district heating pipelines only with protective pipe (steel) reaction forces of pressing endanger environs (usually uncontrollable) only up to ca. 40 m pipeline length, large launch trench necessary short pipe elements, high setting period heavy lifting appliance necessary at the building trench
Horizontal drilling (Horizontal hydraulic drilling): Hydraulic drilling	Installation of the pipeline without protective pipe possible also suitable for coverage <1 m Long lengths can be drawn-in Short building time; controllable Little space required on site	only for simple soils high expenditure and effort for bentonite flushing /recycling
Horizontal drilling (Horizontal hydraulic drilling): HDD Horizontal Directional Drilling	Installation of the pipeline without protective pipe possible also for diameter> 1 m Long lengths can be drawn-in short building time; controllable for wide soil spectrum	high expenditure and effort for bentonite flushing /recycling
Pipe propulsion method Unmanned Manned	controllable, high accuracy of position large drillings can be inspected	for district heating pipelines only with protective pipe expensive machines; heavy equipment; requires a large space expenditure on hydraulic transport and recycling high expense for personnel required

5 Building Ground

The composition of the building ground determines the choice of the method for tunnel drilling. Sufficient knowledge on the geological situation is a prerequisite for an economic construction and at the same time for a low building risk. The extent of the geological investigations must be adapted to the complexity of the situation. It has happened that as a result of unexpected obstacles or the flowing-in of ground water the bore hole could not be completed and given up. This danger is greater for drillings of small diameter where the front cannot be patrolled.

The mot important criteria for the evaluation of the soil are:

- Displaceability or solubility – according to whether the process using earth displacement or removal is to be applied

- Transport properties

- Resistance to penetration and friction

- Compressive strength in the area of the abutment of the pipe presses

- Controllability of the propulsion machine

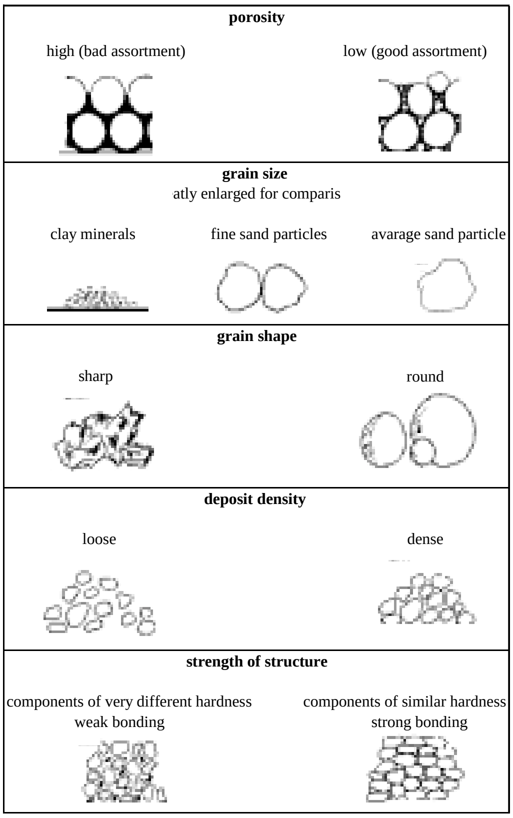


Fig. 5-1: Sedimentary influences on microtunneling

Pipelines for district heat supply are installed in the area near the surface where there is loose soil. Pipelines are seldom laid in completely untouched building ground. Often they lie in areas which were excavated earlier and filled in again. One frequently comes across remains of former buildings.

5.1 Displaceability or solubility

The most important soil properties for pipe driving are:

- Grain distribution or size distribution curve
  the grain distribution is described by the size distribution curve which shows the mass portion of certain grain fractions. Ground with a wide grain spectrum can be easily compacted.

- Degree of compaction
  this is described by the ratio of the actual porosity to the maximum and minimum boundary porosity.

- Perviousness
  the perviousness is defined as the time taken for a quantity of liquid to flow through a certain part of the soil.

- Compressive strength/portion of quartz
  the higher the amount of quartz, the higher the compressive strength of the soil.

- Shear strength
  the shear strength is described using the angle of inner friction and is a measure for the stability of the bore hole

- Chemical composition
  the chemical properties of the ground can change the effectiveness of the flushing liquid.

The properties mentioned are presented in Figure 5-1 [24].

For the classification of the soil types as found on building sites or as building material, there are national standards, e.g. in Sweden Mark AMA 83 or in Germany DIN 18196 etc. Experts from the field of pipeline tunnelling have declared that the classification of building ground for conventional underground engineering works does not sufficiently describe the suitability of building ground for building pipeline tunnels [16]. For pipeline tunnelling more exact information on the following must be compiled:

- the proportion of cohesive materials (share of finest grains)
- the proportion of stones > 6 cm
- the degree of compaction.

These properties can considerably affect the drilling performance of hydraulic drilling methods. (The influence of certain soil properties on the effectiveness of earth displacement methods has already been described in Section 4.2.1.)

5.2 Ground water

Pipeline tunnels, particularly at greater depths, can lie in ground water or in areas where the ground water level changes. Here water can occur as

- seeping water
- backwater or water between strata or
- ground water (perhaps at several levels).

Figure 5-2 shows these in a diagram.

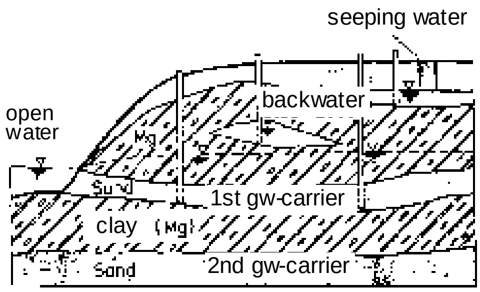


Fig. 5-2: Ground water situation [3]

Important information on ground water behaviour are:

- height of the ground water level
- velocity of flow and direction
- water quantities involved
- chemical properties of the water.

The ground water situation decisively determines the permeability of the soil. The coefficient of permeability is a characteristic determined according to a standard. It varies over a wide range from about

10^{-1} [m/s] for extremely permeable soils
10^{-10} [m/s] for extremely slightly permeable soils [based on DIN 18130].

5.3 Bentonite

Several drilling methods use bentonite as drill fluid, supporting fluid or lubricant. Bentonite is made from pure mineral elements by mixing with water. The elements are mixtures of various clay minerals, which are mainly expandable. The bentonite mixture is adapted to the actual ground properties.

In particular in horizontal hydraulic drilling, the bentonite fills the cavities between the grains in the soil. In this way it supports the bore-hole wall and covers it with a soft layer which aids gliding. With the bentonite filling the bore hole gains a coating, which allows a more protective feeding-in of the pipe than in sand. At the same time, bentonite fills all cavities and guarantees an even bedding of the pipe.

Bentonite coats the grains of soil. The grains are supported against each other and become stable. Even in difficult ground, such as drifting sand, it is possible for the ground to become stable using the correctly adapted bentonite suspension so that a problem-free pipe driving is possible.

For the feeding-in of the pipe the good lubricating properties of the bentonite coating means that the forces required are small and the pipe material is protected.

In pipe driving, bentonite serves as a support and lubricating agent and enables the pressing forces to be reduced and so causes less strain on the pipe.

5.4 Ground risks

In spite of detailed geological investigations it can never be completely ruled out in horizontal drilling that unexpected obstacles occur. Obstacles can lead to increased building costs, and even in individual cases to the drilling being abandoned. Typical risks will be described in the following.

Flat sloping strata: problems with the control can occur when the drilling meets a strata that is at a very small angle to the drilling axis. Often a drill is unable to penetrate a harder layer when it meets it at a flat angle. The tool will be steered into the softer layer. If the driving is not controlled there is a danger that the tool will deviate and even get lost.

Coarse rock and debris: if the drill is hindered by large stones, etc. then it is basically possible either to cut through the obstacle with suitable tools or to go round the obstacle. Although circumvention can be successful at first, there is always the danger that after the drill has passed, in spite of supporting fluid, coarse material from the bore hole wall becomes loose and causes blockage of the drill rods.

Gravel pockets: for drilling methods, which use bentonite, collections of coarse, pervious, gravel or rubble, very loosely packed soil or ground which is full of fissures conceal the danger of high bentonite losses. Unexpected high bentonite consumption can lead to cost increases and cause delays. In some cases such ground can be improved by means of injecting cement grout or artificial resin.

Electromagnetic influences on controls: smaller drills have locating systems, in which a transmitter sends out electromagnetic signals, which are used at a receiver at the surface to locate the drill head. Such a system can be permanently jammed by electrical potentials. For this reason care should be taken in the area of electric railway installations and trams, etc.

Although the risks connected to trenchless pipeline construction should not be exaggerated, this section should make it clear that microtunnelling involves additional uncertainties compared with building in open trenches.

6 Forces during Installation

For district heating pipelines with a polyethylene jacket, the frictional forces, which occur while the pipe is being inserted in the ground, have been the subject of extensive investigations in recent years. The frictional forces occur when the pipeline is lain in open trenches and the ground carefully compacted again after laying. These frictional forces are high; they can be calculated for sand bedding based on [27] as follows:

$$F = \mu \cdot 0{,}75 \cdot \sigma \cdot g \cdot h \cdot \pi \cdot D_c$$

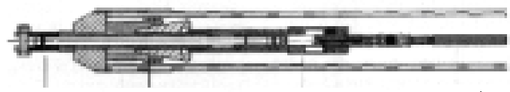
(This equation does not take into account the own weight of the pipe and is only valid for laying depths of up to ca. 2 m.)

However, for trenchless pipeline construction, district heating pipes are inserted into a completed bore hole so that much lower frictional forces are to be expected. The pipes are almost always inserted in bore holes with a somewhat larger diameter than the pipeline and often the bore hole is additionally filled with bentonite, which serves as support fluid as well as lubricant. In this case, the frictional forces are considerably lower than those calculated above, e.g. by a factor of 10. In so far a frictional force calculated above can only be used for extreme considerations. Measured values found in practice are summarised in Table 6-1.

PE-jacket is only supported to a limited extent by the relatively soft foam. Traction must therefore be carefully controlled during the installation.

A traction measuring device, which continuously measures and registers the traction during installation, is inserted between the traction head and the pipe. The device is integrated in a pipe-shaped body which is pulled through the bore hole at the front of the pipe being installed.

Fig. 6-1: Traction measuring device [8]



Before being installed in the bore hole, the pipe material must not show any signs of distortion. If necessary, the front end of material on a roll must first be aligned.

If pipelines are installed in open bore holes, they lie with their own weight on the sole. If the bore hole is filled with bentonite, the pipe swims up and with the buoyant force comes up against the top of the bore hole. These forces are only relevant for possible damage to pipes of larger nominal diameters, about from DN 200. The buoyant force and hence the stressing of the pipe surface can be reduced by filling the pipeline with water in the installation.

Table 6-1: Traction of the installation of district heating pipelines in a bore hole coated with bentonite, measured values

Location	DN	PE-pipe Outer diameter [mm]	Length [m]	Pipe system	Depth [m]	Installa-tion forces [kN]	Source
Stuttgart	80	178	100	Flexwell		19	[15]
Lübeck	450	630	288	Preinsulated pipes	10	160	[28]
Hannover	200	400	260	Steel jacket pipe		80	[26]
Hannover	125	125	180	Flexwell		35	[29]

Installation forces should not damage the pipeline. The pipe outer jacket for all pipe systems, which are available today, consists of polyethylene. The PE-jacket is in danger of being damaged by hard obstacles, sharp stones etc. Steel jacket pipes with their robust steel jacket are the most resistant of all systems used today. The standard pipe, the preinsulated pipe, is more at risk from external influences as the

If high forces are expected, because for instance long lengths of pipeline have to be installed or

when higher resistance is expected as a result of curved paths of the bore hole, then it may be necessary to check the load capacity of the system.
Systems with steel medium pipes can be installed on a steel pipe. Compound pipes with plastic medium pipes can also be installed in horizontal bore holes, however, for long lines, a distribution of the traction between the medium and jacket pipe should be ensured, as the plastic pipes only have a low load capacity .

For preinsulated pipes, which are installed on a steel medium pipe, a shear stress occurs between the medium pipe and the PUR-foam. This is a static load on the cold pipe which is only effective during installation. For this stress the standard EN 253 allows a limiting value of 0.12 N/mm². This value is sufficiently high so that a break can be excluded during installation.

7 Particularities of District Heating Building Sites

The higher construction costs of district heating pipelines in comparison to other supply - pipelines have essentially 3 causes. First, a double pipe is needed for supply and return pipeline. Secondly, pipelines have a relatively large cross-section mainly as a result of thermal insulation. Thirdly, the pipelines expand as a result of their operating temperature and this expansion movement must be taken into account in the pipe bedding. The first two requirements in particular influence trenchless laying.

7.1 Underground engineering

Trenchless pipe laying is interesting where the reparation of the broken open surface is either very expensive or, perhaps, not allowed at all. Examples of these are not only expensively paved pedestrian precincts, and important roads in towns, crossings over motorways and railway lines but also gardens, parks and protected landscapes. Less meaningful appear to be the trenchless construction in new housing estates where together with road building pipelines are also laid. Here, the pipeline laying in open pipeline trenches perhaps at the same time as the laying of other supply pipelines much cheaper. Equally uninteresting is this building technique for large transport pipelines. As these are mostly lain in unfixed or unpaved areas it seems that trenchless building here is not competitive to conventional building in open trenches.

For underground engineering it is essential to know whether it will be a pipeline for supply or for house service connections. House service connections have small nominal diameters, lengths are usually from 10 to 15 m and can be laid in a straight line from the pipeline to the house. The surface above them is road surface, paths and frequently front gardens. For these pipelines with small diameters the earth displacement methods, in particular the earth displacement hammer and hydraulic drilling are suitable as drilling methods.

Supply pipelines are usually larger and can have more or less any nominal diameter. They usually lie under the roadway of town's streets and seldom in the area of pavements or fixed areas. Its segments are about 100 m, and the line can be straight or curved. Only for the smallest of these pipelines is the construction of a bore hole through displacement possible. For larger pipelines drilling methods with earth removal are absolutely essential, see Table 4-6.

District heat networks usually develop in built up areas in such a way that first supply pipelines are laid and, in the following years, the surrounding buildings are successively connected. As the main pipeline has to be opened up for the connection, for cost reasons, the supply pipeline should lie at the normal depth of 80 cm. Larger laying depths, which for horizontal drilling are cost-neutral or perhaps even cheaper, as they reduce the danger of effects on the surface would make connections to customers more expensive.

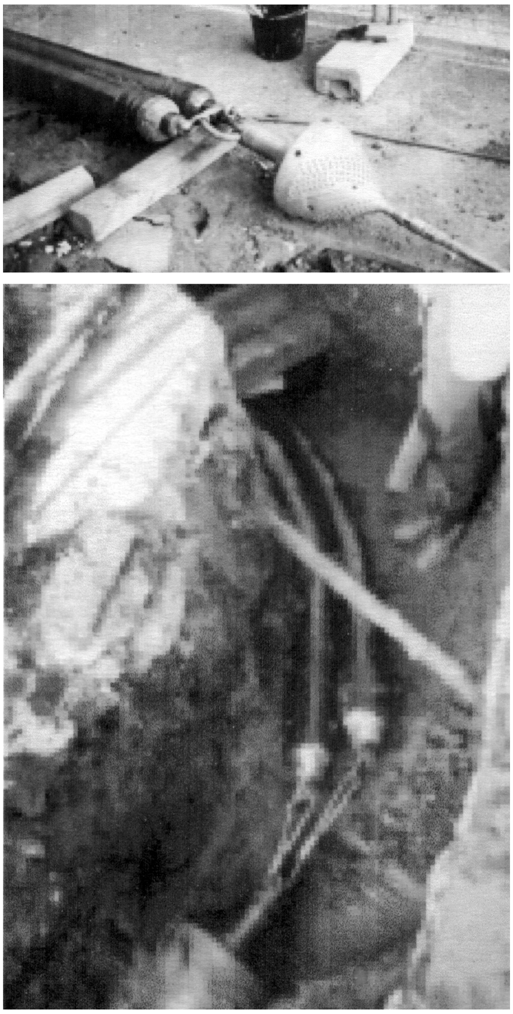
As district heating networks are usually lain in densely built-up areas, manoeuvrable, small building equipment should be preferred. The space available is often insufficient for large building machines particularly as the handling of the pipeline to be installed also requires additional space. It is favourable when sufficient space is available so that for the rigid pipe systems the pipe length can be completely assembled, tested and laid out so that it can be quickly brought into the horizontal bore hole. This takes place usually after the last opening out of the building trench. If necessary, part lengths have to be prepared so that they can be connected together during the installation of one segment. Flexible systems, in which the pipe material is taken from a drum, are here essentially more easy to handle than rigid systems.

7.2 Pipeline technique

Pipeline lengths for supply and return flow, which are usually arranged next to one another side-by-side, are installed one after the other in trenchless laying processes. For large pipelines the laying in two steps is absolutely essential. For smaller pipe nominal diameters up to about DN 150 there are two simple variants:

1. The horizontal drilling is made so large that it can take both pipes for supply and return flow. The pipes have to be installed together and lie in the bore hole directly in contact with one another. Figure 7-1 shows pictures of this method of laying.

Fig. 7-1: Installation of supply and return flow pipelines in one common bore hole [29]



Should branch pipelines have to be connected to such a pipeline at a later date, then the pipelines have to be separated so that the connecting sleeves on the jacket pipes can be made without any problems. A certain flexibility of the pipe material is absolutely essential for this.

2. An alternative to this is to lay twin-pipe systems. Geometrically these are particularly favourable for installation in bore holes. Twin systems for pipelines with plastic medium pipes are offered up to DN 40; preinsulated pipes as twin pipes are seldom in use outside Finland. When using twin pipes, additional care must be taken that the pipeline does not become twisted.

Of all the normal district heat pipeline systems found on the market, the flexible systems are particularly suitable for installation in horizontal bore holes. However, in addition other steel pipelines can be used. Flexible systems have the advantage that the pipes are available as endless material, i.e. in any length, and when rolled up require little space at the building site. The launch and target trenches can then be somewhat shorter.

Primary systems with plastic medium pipes are considered to be flexible. However, of these, only compound system are suitable for installation in horizontal bore holes. Moreover, for nominal diameters up to DN 25 there are compound pipes with a thin-walled, soft annealed steel pipes, which are specially made for house service connections and have better physical properties for installation in bore holes. The steel jacket pipe "Flexwell" from the company Brugg Rohrsysteme with its corrugated jacket and medium pipe is also flexible. In a series of trenchless district heat constructions it was preferred because of its high longitudinal strength. The essential disadvantages of flexible systems here are that the connecting elements needed for the Flexwell pipe are expensive. On the other hand, pipe systems with plastic medium pipes are only tension-proof to a limited extent. There is also a system with a corrugated stainless steel medium pipe (Brand Casaflex) which can withstand limited tension forces. It can be used for installation in bore holes up to 15 m in length.

However, it is basically also possible to install rigid pipe systems, preinsulated bonded pipes or steel jacket pipes in horizontal bore holes. Even these pipes are considerably flexible, if one takes advantage of their deformability up to the elastic limit. For pipes of small nominal diameter only low forces are necessary. The smallest radius of curvature for which no plastic deformation occurs is about 5 to 25 m for pipes DN 20 to DN 100.

Generally when installing a steel district heating pipe in a curved bore hole one does not have to fear that the medium pipe will be overloaded above the 0.2%-stress limit. For the horizontal bore hole is driven with a steel rod that is also not allowed to be overloaded. Moreover, the steel medium pipe is usually considerably smaller than the bore hole diameter and therefore allows greater deflection. However, the elastic curvature leads to higher friction on the bore hole wall.
The tensile strength of the pipe systems must be carefully determined and is not allowed to be exceeded during installation of the pipeline.

The tensile strength is found from the values of the materials and the areas of cross-section of the supporting components. In so far as this concerns pipe systems with steel pipes the bearing strength of the steel cross-section virtually determines the tensile strength alone. In every case, the traction must be continuously measured and recorded during the installation of the pipeline in the bore hole.

Damage to the pipeline during installation cannot be ruled out completely, particularly as district heating pipelines with their plastic moisture protection and in some cases their thermal insulation of PUR-foam are endangered by mechanical damage. Even if an installed pipe cannot be checked for damage over its total length, the first part of the pipeline which has gone through the whole bore hole can be inspected. If the pipe does not show any serious damage at the front end, one can assume that the rest of the pipeline is undamaged.

Particularly at risk from damage during installation are any connecting sleeves. From several scientific investigations, it is well-known that the shrink sleeves used today have such a good hold on the jacket pipe that sliding movements in the ground do not endanger the adhesion between sleeve and jacket pipe.

However, it is well-known from pipeline building that sleeves on pipe rods have been particularly well-protected. One possibility is to protect the edge between the jacket pipe and the shrink sleeve with an additional shrunk-on shrink collar on the one side. A second possibility, offered by the supply industry, is to attach a solid, fibreglass-reinforced cover at the transition from pipe to sleeve, see Figure 7-2.

Fig. 7-2: Fibertec horizontal drilling kit (Photo Frankenplastik)

Finally, for every application the decision has to be taken, whether a protective measure is necessary and, if so, which one is meaningful.

8 Planning Pipeline Tunnels

There are considerable risks connected to trenchless construction as the building trench (front) is usually not accessible, expensive equipment is used, and the forced abandonment of a bore hole, that cannot be completed, represents a great economic loss. For this reason, horizontal drilling must be carefully planned technically; the use of all available information on the building ground is essential. The workability of the ground, obstacles and foreign bodies, determine the cutting process (mechanical or hydraulic) and the building time. They also considerably affect the stress on the pipe envelope.

The engineering effort has to be adapted to the building task. Small pipeline tunnels for house service connections do not require much planning by the supply company. It has been proved that the building management with the building contractor can decide on location whether the house connections should be carried out in open trenches or in tunnels. On the other hand, supply pipelines over longer pipeline segments require careful technical planning by engineers, and for very large building projects it goes without saying that all available possibilities for minimising the building risks have to be taken. In the following section, essential steps in technical planning will be described, whereby large projects with their particular efforts will not be considered here.

8.1 Preparatory planning by the owner

First of all the owner must define the pipeline and its function and determine the position. Detailed decisions on the drilling or installation techniques should be avoided in the early stages. The exact decision on the position of the line should be taken later in co-operation with subcontractors who will carry out the work. Then a cost-optimised solution can be worked out with all involved taking into account the available equipment and experiences from other building sites. In determining the preliminary pipeline route, the minimum radius of curvature and the allowed deviation in position have to be fixed. Possibly there will be a greater tolerance for the horizontal deviation than for the vertical direction.

Usually invitations to tender for horizontal drillings are based on descriptions of performance, flat rates (functional) invitations to tender are the exception. Detailed invitations allow the responsibility to be taken for the ground risks, usually borne by the owner, to be allocated clearly. A secure basic calculation makes it possible for the subcontractor to be able to make his overall cost calculation cheaper.

The owner should determine:

- the building ground conditions
- the position of neighbouring supply pipelines and installations
- the position of neighbouring buildings
- the ground water conditions.

Moreover, the owner is responsible for the approval and licences necessary from the authorities, and perhaps permission to use private ground and public roads.

8.2 Technical planning

The technical planning should be the responsibility of expert companies with specialised know-how, and who have an appropriate capacity at their disposal. The co-operation with a locally experienced building ground specialist is necessary.

After the building measures have been invited to tender on the basis of the owners draft, the proposed solution must be optimised in co-operation with the bidder, who should be requested to work out alternative solutions, which optimally use all of his available resources in experience and material. This frequently leads to economically more favourable variations.

In particular for larger building measures and for unknown ground conditions, exploratory borings are carried out if required to investigate the building ground. The test bores are made outside the planned pipeline route, mostly with separations of 25 to 100 m. The lateral distance from the pipe route is from 5 to 8 m, whereby the test bores are distinctly under the sole of the drill hole. After the soil has been removed, the bore holes have to be filled in again with material that swells up.

The description of the performance offered should be clearly classified. For controlled horizontal boring the classification of tasks into the following divisions has proved itself, [according to 30]:

- Preparation of the site

- The building site equipment
  incl. launching and target trench, if necessary, abutment, setting up of drill

- Drilling work

- Preparation of the pipeline
  Assembly on the mounting and launching way

- Introduction of the pipeline
  Installation, auxiliary equipment, flooding for buoyancy protection

- Quality control
  Control measurements, pressure test, position control

- Clearing the building site
  Disposal of bentonite

- Renewal of surface of area

If contamination is to be expected, an environmentally acceptable disposal of any soil removed has to be undertaken. (In this case, earth displacement drilling methods are advantageous as then disposal is unnecessary).

It is recommended when offering tenders for drilling work, that certain special agreements are made:

The main contractor should be the company which carries out the drilling with his own personnel and equipment. If this is not possible and the drilling company is a subcontractor, then at least he should name the specialised experts who are to be responsible for the drilling. It must be possible to contact those responsible during the whole building process.

The contractor has to base his offer on the description of the building ground provided by the owner. Should he realise that this description is not sufficient, the contractor must obtain supplementary information from the owner. If the actual situation is different from the description, then extra costs must be borne by the owner.
Proof of different properties have to be produced by the contractor.

The building risk in the phase of the pipe introduction is with the contractor.

As in horizontal drilling it can never be completely ruled out that unforeseeable complications can occur, reserves should be included in the planning of time and personnel. The introduction of the pipeline should be scheduled so that it is possible to continue working in the case of delays. A building project is partly completed when the pipeline has been introduced. A premature removal of personnel and equipment must be avoided. In case of difficulties there must be the possibility to act at once. For this, the team with equipment will have to be available.

To guarantee a quick development of the drilling work, all important details have to be decided by the owner and contractor before work is started. A check list, that has proved its worth, for the organisation of a building project between the different parties is given in Annex 3 [30]. This list has to be adapted to the building situation.

8.3 Labour safety

Bore holes for pipelines are usually driven with remote controlled equipment, without personnel being at the front. Large bore holes can be patrolled, for instance for inspection or to remove disturbances. The German safety regulations state that [10]:

- Pipes with a free space diameter of at least 0.8 m may be inspected down to a depth of 50 m
- Pipes with a free space diameter of at least 1.0 m down to a depth of 100 m
- Pipes with a free space diameter of at least 1.2 m may be inspected without any depth restriction.

In addition, precautions for the stability of machines have to be made and all other safety regulations for building sites are obligatory.

9 Practical Experiences with Trenchless Construction of Pipelines

9.1 Technique

Trenchless pipeline construction requires the unusual co-operation between an underground engineer specialised in horizontal drilling and pipeline builder. Both trades work under special boundary conditions. In order to take advantage of all the cost advantages of trenchless laying, it is necessary to integrate both trades in the planning right at the very beginning and to take into account their peculiarities (space requirement for equipment and auxiliary apparatus, working area, characteristics of the trench, pipeline building etc.).

Drilling work can be carried out more reliably the more accurate the nature of the building ground is known. The following have to be clarified:

- the geological situation by means of geological maps
  geological reconnaissance of the outer field in open trenches near the pipeline route
  profiles of the ground in the trench by means of soundings

- the position of other pipelines and underground installations plans of pipeline authorities

Should there be notable uncertainties in the assessment of the building ground, then it has proved to be worthwhile exploring the underground additionally with electronic trenchless methods (Georadar). With georadar, metallic and non-metallic bodies (pipelines) can be located as well as strata in the ground. Ground exploration requires special know-how to operate the complicated equipment and so should be carried out by specialised companies [20].

The classification of the soil according to the plan in Appendix 1 is simple, but has been objected to by drilling companies as this plan does not have sufficient information for working through the ground. A detailed description of ground properties is considered necessary, based on DIN 18319 [13] for instance, see also Section 5.
If the pipeline route has been carefully explored, then the danger of damaging external pipes during drilling is low. In horizontal hydraulic drilling with bentonite there is a danger that the bore suspension flows out uncontrolled. This danger is greater in light soil and in roads with only a thin road surface. Nevertheless, in exceptional circumstances an unwanted outflow of bentonite can occur even at coverage of several metres.

Only tension-proof pipes are suitable for being introduced as a pipeline into a bore hole, for instance, no plastic pipe material without a compound arrangement between the medium and jacket pipe.

About 10 years ago, the first district heat building sites for trenchless laying in Germany were carried out with tension proof flexible pipe material (Trade name Flexwell [29 and others]). Meanwhile plastic medium pipes are also being installed in horizontal bore holes, see as examples [15, 26, 28, 29]. The rigid steel pipe systems are assembled using their elastic deformability, similar to the case in pipeline building. The pipeline is assembled at the mouth of the bore hole and introduced into the bore hole under so little strain that the elasticity limit of the material is not exceeded. Should large traction forces occur, which lead to a notable load on the strength of the material, then the traction must be particularly carefully controlled.

The quality of the installed pipe cannot be reliably tested. There is only the possibility to inspect for damage the front end of the pipe which has been pulled through the whole bore hole. If necessary, a seriously damaged piece at the front end of the pipe can be removed.

In trenchless laying it is never completely out of the question that neighbouring pipelines will be damaged. However, experience shows that this type of damage occurs very rarely when the work is carried out with care.

Deviations from the planned position of the completed bore hole are not negligible even in the case of controlled horizontal hydraulic drilling. The manufacturer promises tolerances up to 5 cm, on the other hand users report that even 10 cm cannot always be attained [20, 16]. A separation of at least 50 cm is foreseen for obstacles.

Finally, from the practical applications, here is a summary of a few more general aspects. Processes requiring large, bulky equipment can create space problems for district heating building sites, which mostly lie in town streets. Hydraulic drilling methods leave the trench contaminated with bentonite. Bentonite must be removed and disposed of. If a drilling method needs large trenches, all possible cost advantages of underground building become smaller. In general, cost advantages of trenchless laying are difficult to realise. For example, it has been shown at the building sites of MVV Mannheim, that with the help of trenchless building techniques rationalisation potential in conventional techniques could be forced. After the advantages of trenchless building were proved in the building of 2 small local gas networks, other companies developed an economic trench for conventional techniques that was once more even cheaper.

Purely practical experiences with trenchless construction of district heating pipelines confirm important advantages compared with open construction. The way the customer, the community and the supply company, assess trenchless construction is found in [14] and summarised in Table 9-1.

Table 9-1: Advantages of trenchless pipeline construction from the point of view of those involved [14]

Advantages for the customer:
- Avoidance of breaking up drives, yards, etc.
- Avoidance of disturbing gardens, protection for trees and plants
- Reduction in building noise and dirt
- No disturbances on driveways and parking places
Advantages for the community:
- Low hindrance to traffic
- No damage to roads
- No costs to repair roads
- Less settlement damage
- Short building time
Advantages for the supply company:
- Short building time
- Less finishing work on the road surface
- Less soil removed and lower demand for disposal
- Customer-friendly building development
- Reduced danger of accidents

However, disadvantages are also recognised:

- costs for horizontal drilling are still high today
- building equipment is often too bulky
- the pipe system must be able to endure high traction
- the pipeline cannot be inspected and tested for damage
- lower accuracy of position

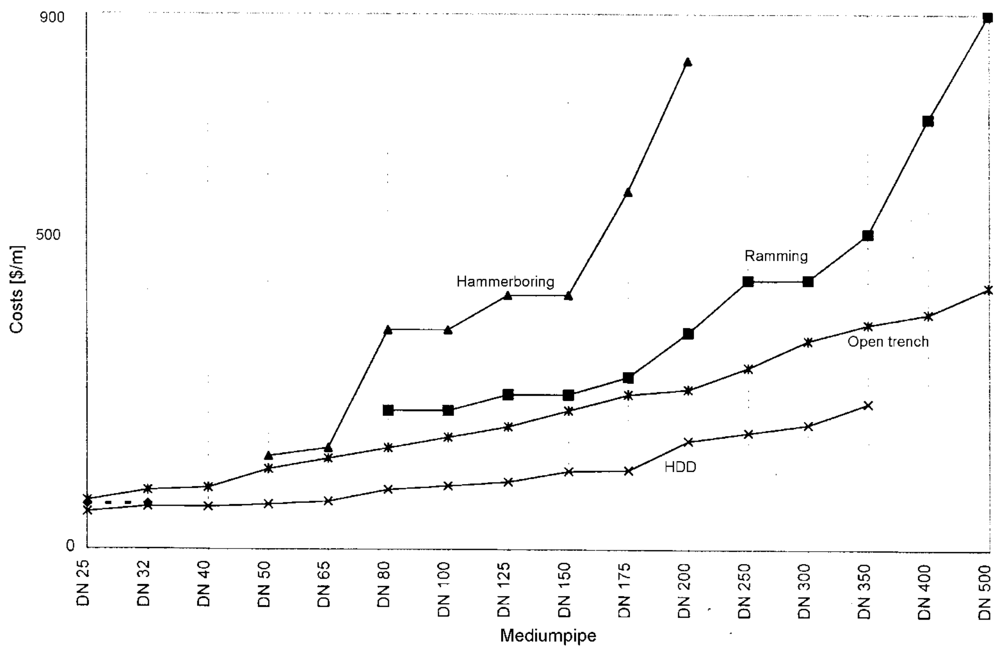
9.2 Construction costs

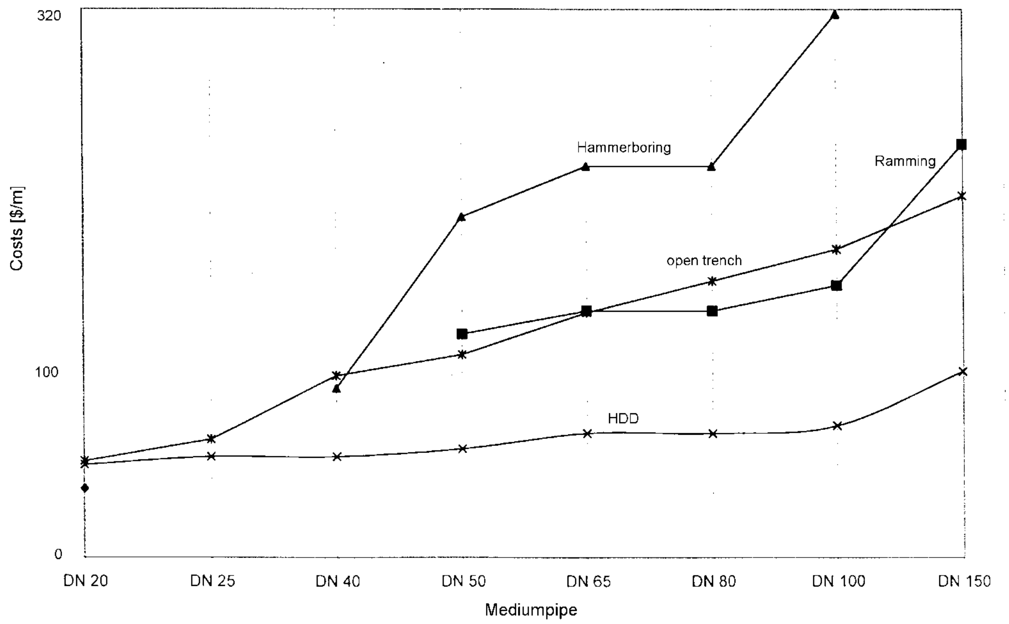
A cost comparison of the pipeline construction in open trenches with the trenchless method is made more difficult because horizontal drilling is still a young process. It is still not being practised with the same routine as conventional pipeline building; only then would a reliable comparison be possible.

From experience it is known that special measures are more expensive than standard processes. Today this is usually still true for trenchless construction, although its promoters can already point to more favourable examples. However, it is important to be able to build not only more cheaply at building sites which would be very expensive if conventionally built, but that cost advantages can be achieved even under normal building situations.

Sweden has investigated innovations in pipeline building concerning trenchless constructions [19]. Underground engineering costs, which could be achieved by the different drilling methods, were estimated. The HDD-method and the earth rocket were presented as competitive to conventional building. The top of Figure 9-1 shows the costs for horizontal drilling in comparison to conventional laying in open trenches. The diagram at the bottom represents the cost situation if instead of a single pipe a twin pipe is lain.

Fig. 9-1: Underground engineering costs for district heating pipelines in trenchless laying
top: supply and return as single pipe
bottom: twin pipe





In order to understand the cost comparison it must be stated that only the underground engineering costs are presented and no costs for pipe material are included. 40 m long pipe sections for preinsulated pipes of the insulation series 2 were compared.

Ramming and hammer drilling show very high costs because they install a protective pipe and therefore present a high-value solution. The hydraulic drilling method causes costs which are about half those of conventional building costs. This favourable assessment arises mainly from the assumption that only one bore hole has to be constructed in which both pipelines can be inserted. Generally this method would hardly be practicable for average and large pipelines.

Over several years, a supply company in the west of Germany has constructed a large number of house service connections using the closed building method with earth rockets [31] and has achieved cost advantages for the underground engineering. Figure 9-2 shows a comparison of the underground engineering costs for house service connections for trenchless and conventional building. If the building sum is weighted according to the length of pipeline laid (total of ca. 3.5 km) then one obtains a cost advantage for trenchless laying of 17 %.

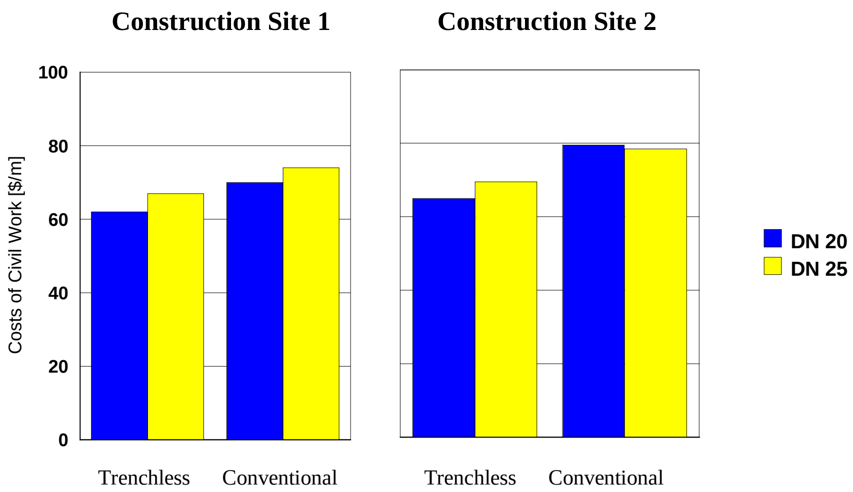


Fig. 9-2: Comparison of underground engineering costs for trenchless and conventional building of house service pipelines

The drilling companies can see further cost reductions in the future for their performances. This appears to be possible as horizontal drilling is a new discipline, which must still have considerable potential for further development.

References

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Appendices

Appendix 1:	Classification of soil and rock
Appendix 2:	Overview of the terminology
Appendix 3:	Check list for the organisation of building progress of a horizontal bore hole

Appendix 1: Classification of soil and rock (Distribution according to DIN 18300)

Class 1	**Topsoil**
Class 2	**Drifting types of soil** liquid to pasty, poor elimination of water
Class 3	**Types of soil easy to dissolve** sand, gravel, sand-gravel mixtures with up to 15% cohesive material, max. 30% stones between 63 mm and 300 mm
Class 4	**Types of soil fairly easy to dissolve** mixtures of sand, gravel, clay and silt with more than 15% cohesive material, max. 30% stones between 63 mm and 300 mm
Class 5	**Types of soil difficult to dissolve** soil according to classes 3 and 4, more than 30% stones between 63 mm and 300 mm, max. 30% stones between 300 mm and 600 mm, plastic clay
Class 6	**Types of rock easy to dissolve** mineral rocks, with cracks, fissures, weathered, ground with more than 30% stones between 300 mm and 600 mm
Class 7	**Types of rock difficult to dissolve**

Appendix 2: Overview of the terminology

Name	German	used in
NoDig Trenchless Installation and maintenance of underground pipelines; Laying, surveying, restoration	NoDig Grabenloses Bauen	Journal NoDig ISTT
Microtunnelling Small tunnels for supply lines, unmanned and non accessible	Pipeline trenchesbau (nicht begehbar)	Literature
Trenchless laying Trenchless construction	Trenchless construction. Geschlossene Bauweise	DIN EN 12889 Literature
Horizontal Directional Drilling HDD; Directionally Controlled Boring; Mostly hydraulic cutting, but dry boring also possible	Gesteuertes Horizontaldrilling methods; (Richtbohren;) HDD oft nur Horizontal wash drilling for Großbaumaßnahmen	Literature
Soft boring = hydromechanical boring		
Horizontal wash drilling method	Horizontal wash drilling	E&P 2000
Earthhammer	Earth hammer Bodenrakete	
Pipejacking Pipepushing Pipedrilling	Rohrpropulsion	DIN 18319; DVGW

Appendix 3: Check list for the organisation of the building progress of a horizontal bore hole [according to 30]

The following details should be fixed in writing by owner and building company before work starts:

- Ground stability in area of launching and target trenches
- Earth consolidation for instance in the case of a limited, not self-supporting bore hole
- Securing the bore hole mouth in the area of insertion and exit
- Overcoming ground water conditions
- Drilling the bore hole
- Working the earth
- Earth transport
- Pilot drilling
- Reamer actions
- Time schedule for all working steps mentioned and standstills without risks

- Launching way, assembly of pipeline
- Organisation of launching way Assembly of pipeline
- Prevention of damaging torsion during insertion
- Pipe bundles
- Insertion process for the pipeline, forces, radii of curvature
- Covering the connecting sleeves
- Testing for damage to the cover and repair
- Buoyancy or downward pressure protection

- Building ground and environmental damage
- Preventive measures to protect the building ground and the environment

- Filling of abandoned bore holes
- Method
- Filling material
- Proof of quality of the filling

- Disposal of supporting fluid
- Proof of safe disposal

- Treatment of obstacles
- What is planned when obstacles occur?
- What obstacles can be driven through?
- After how long will the attempt to drive through be abandoned?
- Determination of the extent of the obstacle
- What distance from the obstacle is a new drilling planned?

- Building schedule
- Calculations
- Stress conditions during the different building phases
- Traction during insertion
- Lift / downward pressure protection
- Statistical proof for trenches, anchorage, launching way and other supporting constructions
- Proof of pressure and peel strength of covers

- Plan of execution
- Plan of execution with the intended progress of the boring in vertical and horizontal position, taking into account the boundary conditions given in the invitation to tender.
- Presentation of the trench, anchorage, launching way, roll frames and auxiliary constructions
- Building site organisation plan with deposit and storage areas

- Securing evidence and documentation