Trenchless technologies in pipeline construction

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1. Development and significance of pipeline construction

Pipelines are a rather economical and eco-friendly way of transporting liquid and gaseous fluids, like natural gas, water, oil or district heating, covering long distances. Pipelines transport huge amounts of energy safely, quickly and economically. This is an extremely gentle and efficient way of transportation. High demands on operational safety and the equipment used, as well as regular intensive checks of the operating process, applying the latest techniques, assure the high safety standards of this transportation system.

If the water supply is nationwide, water galleries and transport lines installed underground connect the source to the storage and distribution spots, which are often far away. Pipelines transport oil and gas from the exploitation area to the plants for further processing. The products are handed on to the industrial or private user via further transport and distribution lines or distribution networks.

Producing countries and pipelines for water, crude oil and natural gas have been in the spotlight of geo-political objectives and development at all times; economical development and growth are based on them, as well as dependency towards trusts and politically motivated decisions.

Mainly decisive for the concept, construction and operation of pipelines are not always distances and technical or operational expenditure, but rather amounts of delivery, consumers contracts or, finally, political decisions. At least in Europe, cross-national economy pacts are founded, replacing nationally orientated autarky attempts. The EU tries to cross-link producers and consumers of oil and gas products via pan-European transportation corridors, in order to guarantee the supply from several different markets.

Drivers of the global energy monopoly are the international energy groups, who act as multinational major coorporations, either under private or governmental direction, depending on their political background. Surely, it is difficult to separate the area between government interventions and independent decisions made by the group; crude oil and natural gas have been the lubricants of the economy at all times, therefore they are also the base of development in the producing and consuming countries.

1.1 The first pipelines – historic reflections

According to a page in the internet, in the former times of Greek civilisation, the probably first „pipeline“ in history was installed because the Cirò, one of the oldest Italian wines, was conducted directly to the hulls of the ships in special ceramic pipes.

Another excursion through the history of pipeline construction leads us to a brine line between Reichenhall and Traunstein, which is seen as the oldest pipeline, according to our present definition of the word. This line, built between 1617 and 1619, had a length of 31 km and consisted of 8,500 pipes made of wood, each 4 m long. The 238 metres of height between Reichenhall and Inzell were surmounted by water wheels of 7 metres height and driven by water power.

In the 19th century, 1860 important water reservoirs were found in the region of today’s Grampian National Park in Victoria, Australia. There, between the valleys of Mount Williams and the Sierra Ranges to Stawell, the first pipeline for potable water was built, with a length of more than 30 km.

Another important line was also built in the north-west of Australia, it is the largest drinking water line in the world. The discovery of gold near Coolgardie in 1892 and Kalgoorlie in 1893 lead to the construction of the Golden Pipeline. 566 km of pipeline altogether, made from 66,000 steel pipes, 760 mm in diameter, with lengths of 8.50 metres each, were installed underground from 1898 till the official opening in 1903. To this day, approximately 350 km of the original Lock Bar Steel Pipe are still in use.

1.2 Oil – the Black Gold

The search for the black gold became the main driving power for adventurers and businessmen alike to build pipelines. Since the 15th century, kerosene for lamps was gained from oil sources below the ground. It was in 1848, when the first oil well of the world was drilled in Baku, followed by the first refinery in 1859, also in Baku. Modern oil production really started in 1872; there is only one production plant in Romania which is an older one.

Baku had developed into one of the largest industrial cities in Russia. At the end of the 19th century, the first oil boom in Baku broke out, when the Nobels and Rothschilds came in to town to challenge the Standard Oil Company of John Rockefeller. They built the first pipeline in 1897, running from the Caspian Sea to the Black Sea. More than half of the oil on the world markets came from Baku 100 years ago.

The first oil drills in the United States were carried out in 1857. The first pipeline in the USA was built in 1865, with a length of 8 km and a daily flow rate of 250 tons. As a result, the United States became the dominating producers until the mid 20th century, and were almost self-sufficient at that time.

Today’s structures in the producing countries were established in the middle of the last century, and it was not before 1967 that the first crude oil from the North Sea could be processed by British Petroleum.

In 2005, huge pipeline systems, like the BTC- Baku - Tbilisi - Ceyhan with a length of 1,760 km, will start service, to supplement the current shipments with ultra large carriers for oil. Parallel to the BTC-Pipeline, the South Caucasus Gas Pipeline (SCP) is being installed in the same pipeline corridor between Baku and Erzurum (Figure 1). Large projects, like the Alaska Pipeline, the Mackenzie Valley Project in Canada or the pipeline from Siberia to Japan and China, are all in various stages of preparation at present.

1.3 Natural gas – a further source of energy

Besides the mineral oil, with its differing chemical compositions and corresponding exploitation and conditioning expenditure, natural gas is steadily gaining importance as a clean energy. In earlier times, it was flared a waste product during mineral oil production, but now it is gathered along or even...
 searched with separate exploration bores.

At present, large gas deposits are found and exploited in the traditional oil producing regions, as well as in North Africa, China, Australia and in the whole Pacific Region (Figure 2).

Not only the producer and consumer countries, but also the transit countries are in the direct focus of international decisions. Turkey, for instance, is already seen as a turntable for oil and gas from the Caspian Region and the Middle East, and also for gas from Egypt. With the help of new installations or the connection of already existing pipeline systems across the Balkan, these raw materials are planned as a part of the European supply.

The gas supply between South and North America, just as between Australia and China, is managed by liquid gas transports, but more and more also by the construction of new lines. More feeder lines to new industrial centres or distribution networks in Chinese towns with more than a million of inhabitants are being installed along transportation lines, i.e. the 4,000 km long West-East Pipeline, which is already in use.

1.4 The beginnings of HDD in pipeline construction

The exploitation, but most of all, the transportation of oil and gas would never have been accomplished without the development of the vertical drilling technique and the trenchless installation methods. We have heard of drilling attempts carried out by the Chinese as far back in time as 600 B.C.; 1420 saw the first bore trials in Europe and at the end of the same century, Leonardo da Vinci developed the first machine for horizontal drilling, which could drill through wooden trunks to produce water pipes.

The vertical drilling technique, however, was improved immensely by the exploitation of crude oil by the end of the 19th century. Then, in 1920, the first holes in horizontal direction were drilled in the German hard coal mines, non-steered application could achieve lengths of up to 200 metres into the coal stratum.

The first horizontal river crossing beneath the Pajara River near Watsonville in California was performed with an inclined vertical drill rig by Martin Cherrington. In the time following this event, the company carried out 36 further crossing bores beneath rivers and traffic ways until 1979. 1979 is also the year of construction for the “prototype” of a horizontal drilling unit for near-the-surface application, with a slanted drill rig for installing pipelines.

Halfway into the eighties, the HDD technology came over to Germany and Europe from the States. Meanwhile, the further development of the drilling and steering technique allows drills from a few metres up to 2 kilometres.

The well-known jack & bore methods have established themselves for shorter distances. With the TT technology, you can drive pipes up to 4 metres in diameter. Microtunnelling machines with fully automatic control force open exact bore paths, and the plough technique can also be applied for smaller dimensioned lines.

The development of trenchless technologies has added further economical dimensions to pipeline installation, and our ecology also profits from these techniques. For more information concerning the current state of technology, further developments and their application, contact the manufacturers and suppliers of machines, equipment and fuels. Institutions, like IPLOCA or DCCA and the European sister association DCA are important forerunners of the HDD technology. The relevant professional magazines have always been important sources of information on the latest events and novelties, but also the internet portals, like Nodig-construction.com or the portals of GSTT and ISTT.

2. Utilisation of trenchless installation technologies

The determination of a pipeline course often follows political motivations, especially when projects are crossing several countries, therefore it is not always bound to be the most economical version. This may certainly lead to technical constraints, which demand a certain analysis of the alignment with focus on the installation technologies. The application of trenchless methods may be technically and economically reasonable in just these special cases. It must be the in the interest of all people involved to keep costs low by maximising the share of trenchless techniques.

Precise observation can be worthwhile; in pipeline construction, like in other branches, economic constraints determine the method of action, and in many cases, the utilisation of the technical possibilities of trenchless technology result in shorter working times coupled with a more economical...
installation than would be possible with open trench methods. Already the plough technique for line diameters up to approx. 350 mm has immense advantages, compared to the open trench method. The plough technique is also used in shallow water regions.

The HDD technique makes trenchless line installation possible and is increasingly established in pipeline construction and for laying transportation lines. It is mainly used:
- crossing inshore waters, rivers, canals and irrigation systems
- crossings beneath railway tracks, streets and highways,
- avoiding damaged terrains,
- protecting flora and fauna
- landscape protection and nature conservation regions especially,
- to overcome topographic obstacles or difficult soil structures, e. g. rocks
- wherever obstacles or particularly sensitive parameters make the application of open-cut or other methods like the cable plough technique, difficult or even impossible

Thus the HDD technology is gaining growing economical and ecological importance. A more recent statement concerning the distribution of application areas of HDD technique is also interesting (Source: Underground construction 41, June 2004, Figure 3).

Particularly the linkage of offshore with onshore plants sees the open trench construction, due to its negative effects, increasingly being replaced by the HDD technique. The sensitive transition region, with shallow water zones, strips of shore and flood protection banks, is simply undercrossed from the shore without disturbing flora and fauna (Figure 4).

2.1 From the idea to installation

Years before being started, many pipeline projects already exist as an idea or even as a detailed image. Changing general economic conditions, political decision processes, the struggle to find an ecological route or assuring the financial side are common reasons for long time delays, before the execution of the project may commence.

At a definite time the required measures, from preparation to commissioning, can be carried out within a tight time schedule (see att. Baku – Tbilisi – Cehyan (BTC) – pipeline, Figure 5).

As soon as the political starting shot goes off and a feasibility study has been carried out, the pipeline route, which is able to meet all the requirements of the construction phase and later service life best, is chosen from all possible courses. This choice is based on the Environmental and Social Impact Assessments (ESIA), accompanied by the Government, the general public, the NGO's and the financial backers, like the World Bank, EBRD or IFC. This transaction is time and money consuming; drawing up the documents, their layout, the public meetings, hearings and inspections take a lot of time. The ESIA documents of the BTC
project comprise more than 11,000 pages.

All persons concerned have their own ideas and regulations; to take them all into account or to find compensation, often on a monetary base, is an important step in the direction of achieving the permission and approvability of such a project.

At this stage of the project, it is already possible to minimise many technical and economical risks by applying trenchless technologies. Some examples for this are:

- utilising the HDD technology for crossing sections of the bore path which includes the risk of landslides to avoid destabilisation, which is to be expected with the open cut method
- undergoing inaccessible path sections with long distance installation, this saves elaborate structural measures for establishing access roads
- crossing natural areas worth protecting with the help of underground construction methods in greater depths; time and money consuming discussions with pressure groups are avoided, the protection of nature can truly and constantly be guaranteed
- In an actual case, the utilisation of private property and the payment of compensation could be avoided by applying the HDD method.
- The installation of a line with the HDD technique in great depths helps to avoid a limitation of the utilisation, which would be the natural result of an open trench installation with the usual cover of only a few metres.

All these points show clearly that it is possible to defuse environmentally relevant demands and other constraints at an early stage with the trenchless installation method and to guarantee the feasibility and viability of a project.

### 2.2 Conceptional and aspects environmental

“Throughout the pipelines planning process we have worked to minimise negative impacts on the environment and society”. This sentence in a BTC document already marks the responsibility of all parties concerned at the stage of conception. The basic course for installation and operation of the pipeline is already set at this stage, and this course suggests the trenchless method for line installation.

Therefore, a few of the maximes shall be drawn up, following the plan and construction of the BTC pipeline and the SCP following the same path some time later on.

Economical and social goals are:

- combustion emissions
- no loading or offloading emissions
- zero discharge of oil or chemicals to land or surface waters
- maximising efficiency of net energy exported
- minimizing project footprint (including Right of way (ROW), temporary facilities and access roads)
- no net damage to protected ecological areas or archaeological sites
- no creation of access routes to otherwise inaccessible areas
- restoration of habitat and hydrological regimes
- no loss of containment of product
- no resettlement of local population
- no permanent disruption to the livelihood of the local population

Concrete effects of these principles can be seen in the fact that an examination of the flora and fauna, above and below the crossing area of the river, is carried out before river crossings are established, and the effects of construction and operation of the pipeline is drawn up in an evaluated scale. The decision, in which way the pipeline installation and other measures taken during construction and operation shall commence, is based on these results. The crossing types and the manner of construction, for example, are defined in this way.

#### 2.3 Reflections on the trenchless part

In pipeline construction, the installation of lines in populated areas is generally done underground, still mainly applying open trench methods. The trenchless, closed installation part of the complete bore path length may not be relevant, but it is of great importance to realise that many projects – particularly those with large crossings of any kind – could not be carried out without the trenchless method at all. A dense settlement and valuable surfaces are disturbed in very few places alone, emissions are reduced or occur only on a small scale and small limitations of use are avoided.

The following recent examples may back up these statements. But even the population in apparently unproblematic regions shows increasing sensitivity towards the effects of above-ground construction methods – as is made transparent by the ESIA transaction concerning the BTC pipeline. This development almost forces us to apply the underground installation techniques.

The BTC pipeline, with its total length of 1,760 km (1,091 miles), is divided into 445 km in Azerbaijan, 245 km in Georgia and 1,070 km in Turkey. Crossings in the pipeline path concern

- rivers, canals and other inshore waters
- public roads and pathways
- railway tracks
- underground lines of all kind
- special geological features (like active faults etc.)

As a result, Azerbaijan has 350, Georgia 250 and Turkey 300 crossings beneath railways and roads, river crossings are Azerbaijan 30, Georgia 200 and Turkey approx. 600. Of course this includes all inshore waters, from the rivulet to the dried out wadi to the mountain stream in flood.

In most cases, namely in less sensitive areas of minor importance, these crossings are done with the open trench method. Figures from the BTC section in Azerbaijan clarify the relations between open and trenchless installation: besides seven HDD- crossings, this section with 445 km in length requires the performance of 21 auger borings. Here, the pipeline is installed inside the built-in protection pipe, in order to avoid damage to roads and railway tracks and to disturb sensitive river regions and natural areas as little as possible.

Definitely different relations can be seen in the example of the 354 km long product pipeline from Stade to the DOW Chemical location in Teutschenthal. For this steel pipe, dimensions 273x5.6/8.8 mm, with PE coating, 113 pressings, 9 protection steelpipe pressings and 203 steered HDD drills were carried out, 24 of them were larger crossings of rivers and navigation canals.

When the Alliance Gas Pipeline in North America (length 1,900 miles, 36-inch in diameter) was installed the relations were as follows: more than half of the road crossings were executed in the road bore technique. 13 large river crossings had to be overcome additionally, the HDD crossing of the Peace Rivers, with 4,600 foot (1039 metres), being the most challenging of them all: ramming and HDD technique were combined for this. Microtunnelling machines were also used for the project.

When comparing the Trans Alaska Pipeline System (TAPS) to the Sakhalin II Pipeline, we also get insight into interesting figures. Both lines run through inhospitable arctic regions, but their modes of construction vary.

The TAPS is an oil pipeline, 1200 mm in diameter, pressure 70 bar and 1,280 km long; 673 km of these run above the
ground, 602 km are built conventionally underground, 6 km are equipped with special freeze-protection devices. More than 900 rivers and brooks, 70 of them significant, were crossed by 13 pipeline bridges or open trenches of 2.3 to 4.8 metres, almost 15 metres deep in the most extreme case. No HDD crossings where performed. At the beginning of the seventies this technique seemed unsuitable for such an extreme plan; also, large rocky boulders obstruct the area of the bore path.

Recent experience in the U.S. Arctic (ARCO Colville River Crossing) has only now proved the technology in Permafrost conditions. This project was executed in 1997/1998 and took seasons rather than the single season planned. The analysis of the crossing type (Bridge, trench, HDD) used similar methodology as used by Sakhalin Energy. HDD was chosen as being least expensive (at the time, based on a single season construction.

The Sakhalin II Pipeline consists of an oil and a gas pipeline, 500 mm in diameter each, 600 and 1200 mm in some parts, 100 bar operation pressure and a total length of 807 km. More than 1100 water courses of all kinds, 63 of them particularly sensitive, had to be crossed. Pipeline bridges were not built, instead, there were 8 HDD crossings with covers of up to 10 metres, the others were mainly achieved using the open cut method.

No part of the line was installed above the ground, as Permafrost is not a problem there, and the Russian understanding of security and nature protection is contrary to open lines: Technical failure, or even sabotage, can lead to great damage and permanent interference, if oil emerges from the line. The TSUREN (Russian Federal Regulators) have also experienced, that no HDD was applied for the river crossings, crossings in open trenches were only allowed in the winter months, when the soil was deeply frozen. Tacking stock we can say that the HDD technique, as it is today, is effective and economical in its application, even in extreme conditions.

3 Techniques Installation

3.1 Open trench construction

Naturally, the open trench construction takes the lion’s share of the total length. Figure 6 shows the typical situation. Before the beginning of work, the future path is determined and staked out. After this, the working area is cleared, which means, the removal of any trees and bushes standing within this area which includes the ‘right of way’ area (ROW).

In the case of the BTC, the working space is 32 meters because the SCP will follow at a later date, but in the same corridor a further expansion of merely 12 m of the ‘right of way’ zone is necessary. Here, the principle of using the already existing corridor to protect humans and nature alike, is also applied.

The next step is to excavate a trench, approx. 2.5 m deep, in which the already welded pipe string is lowered later on. Approx. 15 km of open trench are always prepared at this stage. The trench should be backfilled with the same material, especially the cover layer should be the same as before. Then the surface is landscaped and restored.

In the way the building activities and regional transactions of this BTC pipeline project should be organised, the building site claims no more than a length of 60 km during the complete time. The building activities should last for 6 to 8 weeks in each region. During this time, all possible efforts to minimise noise, dust and job site traffic should be taken.

3.1.1 Open Crossings

The crossings of roads, rivers, brooks and railway tracks is often performed using the open trench method. Usually unpaved gravel roads are concerned, which are closed and crossed with the open trench.

Minor roads and railway tracks are crossed by working one half of the way while maintaining the other half for the traffic.

Dry open-cut crossings of small rivers or irrigation canals is carried by means of a by-pass of the water course into pipes; otherwise, the flowing water is simply crossed with an open trench. Decisive factors are the amount of water, function of the water course, effects of the measure on the crossing and downstream area as well as the expenditure required for restoring the riverside and slope area.

Therefore, every crossing demands thorough investigations to find out how to avoid too much disturbance for residents and the environment, how to carry out the measures as quickly as possible and how to restore the disturbed surfaces to their original state in the best possible way.

This kind of application naturally has a strong effect on all persons concerned and the surroundings of the civil works. Even under normal conditions elaborate job site logistics for the parallel-running processes of excavation, installation, back-filling and restoring works as well as the required cross and longitudinal transports in the area of the job site are indispensable. Heat, dust and, most of all, precipitation aggravate the access to the job site and turn work in deep terrain into a strain for man and equipment. Appointed time schedules set everyone under pressure, making additional measures inevitable in order to ensure the completion of the job in time. Here, trenchless technologies – assumed the job site is accessible – are considerably less sensitive; additional equipment of the machine technique allows work even under extreme conditions, i.e. larger cooling aggregates for great heat or heated shelters built above the unit for cold temperatures.

Therefore, the application of trenchless techniques can prevent many negative effects of the open-cut construction, reduce the costs for restoring the original condition and save additional mobilisation of resources for completing the project.

3.2 Plough Technique

In comparison to the open trench method, the pipe and cable plough method is distinguished by reduced
disturbance of the surface, very high daily performance and economic efficiency. Particularly in rural regions, where often the distances are long, free of obstacles and the geology is consistent, this method is unbeatable. When applied under water, the plough is pulled across the sea bed by ship, opening a trench in which the pipe is laid and then backfilled again.

The conventional pipe and cable plough creates a V-shaped trench for installing the pipe, back-fill is performed in the next working step. Ploughs - made in USA - with a pulling force of 330 tons, depths up to 6.5 ft can be achieved in one single working step. The dimensions of this kind of plough: length 75 ft x width 40 ft; pipes up to 45 inches in diameter can be installed.

Similar dimensions - approximately 70 feet wide, 70 feet long and 30 feet high - are the specifications of a marine pipeline plough, which was used for the installation of a 24 inch pipeline with a total length of 35 miles in the Eastchester Extension Project.

These plough methods require rather large working space to the sides, which require a lot of finishing work. The company Georg Föckersperger GmbH, Aurachtal, has developed a basically new installation and pipe laying technique in Germany 30 years ago and is improving the method since then (Figure 7). Up to now more than 50,000 km of pipeline, including steel pipe s up to 350 mm OD and casting lines up to ND 250, have been installed.

A dissertation from the year 2003 determined the loads occurring during installation and converted them into a mathematical formula. Accordingly, pipelines can be laid in a way that eliminates damage to the pipe and nearby lines, allowing great single lengths to be pulled in.

3.2.1 Special Plough - soil conditions

The soil-mechanical processes affecting cohesive and non-cohesive soils during installation have been examined was part of the dissertation mentioned above. Result of this examination: the ideal soil for applying the plough technique is well compactable and sufficiently stable.

Only slight lifting of the soil on the terrain surface occurs, the required total pulling force is low and stress during installation is not severe. Route sections containing boulders, fractured rocks or stones are unsuitable for this method. Soils of this kind can neither be displaced nor compacted. Depending on the bedding, unfavourable loads may occur, influencing the functioning order or the service life of the pipe in a bad way.

The investigation also proved, that the load on the cables and pipes is minimised in comparison to conventional building methods, because the soil is only slightly disturbed. The application range comprises non-cohesive and cohesive soils. Depending on the consistency or ground compactness, the ability to be displaced has an effect on the pulling force during installation. The friction-reducing effects (which also reduce the power requirements) of a Bentonite lubrication can also be favourable for the installation procedure.

Cohesive soils with a soft consistency take longer to settle on the pipe being installed than non-cohesive soils with their loose bedding, cast iron pipes with protruding collar connections are therefore hardly suitable for loose, sandy soils.

3.2.2 Special Plough - mode of operation

Supported by the cable-pulled special plough, the pipeline is laid directly into the void created by the displacement process, which is the advantage of this method. Here, we must differ between the static or dynamic plough method with installation box – the line is lead overhead to the plough share – and the plough towing method. Plough towing means that the line is inserted in the starting pit and – as the word already suggests – is towed underground into the already created plough track.

Simply one little starting pit for setting and aligning the plough is required. The plough blade can be precisely adjusted in its height by hydraulics, allowing progressive adaptation of the ploughing depth to the current needs down to 2.0 m. The towing winch with its pulling force of up to 140 t and a cable length of 130 m is mounted to an off-road vehicle and braces itself automatically when reaching the target.
Plough and plough blade are mounted to a rig with special tyres which can be adjusted in height and track width by means of hydraulics, therefore, application is no problem even in inaccessible terrains or when crossing shallow offshore waters. In 2003, the most spectacular application took place across the north German mud-flats, when a 5 km long water line to the small island Nordstrandischmoor was ploughed in (Figure 8).

Lines with small diameters are also installed, even in bundles, with track warning tape and a daily performance of up to 2000 – 3000 metres. The so-called rocket plough is available for larger pipelines, steel lines up to OD 350 and cast iron pipelines up to ND 250 have been ploughed in until this day. In 2003, a special ATV-DVWK-M139 leaflet was published, which documents all application ranges, requirements and quality assurance.

The plough method is particularly suitable for rural areas with a low population density, great pipeline lengths with only a few connections underground. Up to now, this method has only been used for pressure lines. Crossing small shallow waters and installing pipes in slopes is no technical problem due to the plough construction with universally adjustable wheel extensions.

The utilisation of the plough method has proved its economic and eco-friendly value for pipe installation below ground water level. Unpaved terrain is a precondition and there should be no larger obstacles in the track. Before the installation can commence, the exact position of crossing lines and the underground conditions in the line path must be determined.

The method is remarkably efficient, time-saving and eco-friendly, because the excavation of trenches is not necessary, the track of the plough is simply smoothed down. A very economical, ecological, proven and versatile technique with only minimal underground impact is offered to the customer and user.

3.3 Trenchless Installation

There is a great number of techniques and methods for underground and trenchless installation. They all belong to the category of ramming, fluid assisted drilling and microtunnelling techniques. Mainly roads and railway tracks are crossed with ramming and drilling techniques; the other method, HDD, is also used for undercrossing larger rivers and their foreland.

The trenchless method is the obvious alternative, not only when obstacles occur along the pipeline course, but also when sensitive natural habitats need crossing and damage has to be avoided. The choice of the right method depends mainly on pipe diameter, length of the bore, geology and geo-technical conditions. The dimensions, depth, excavating and set-up of the start and target pits, the size (dimensions) of the required working space as well as the measures for ground water drainage differ from one method to the other.

The composition and structure of the ground in the geo-technical sense is the decisive factor for the completion of any drilling job, a fact, which has to be acknowledged by carrying out a sufficient survey beforehand.

3.3.1 Auger Boring

his bore technique uses a protection pipe which is pressured forward, while an auger removes the spoil at the same time. This method can be used for over 90% of all soil types. However, it is necessary to observe the stability of the soil structure. Non-cohesive soils and large stones cause problems; the first have a tendency to flow, the second must be easily smashed to pieces to keep the passages of the auger unblocked.

If the soil conditions are unstable, the auger flight must be pulled back behind the cutting shoe in order to avoid breakage of the position front. Otherwise the auger can work directly in the cutting shoe area or even be equipped with a cutting head itself, to excavate the path for the protection pipe.

In reference to the size of drillable obstacles, the pipe diameter itself should be either small enough to bore through without upsetting the position, or large enough to recover these obstacles. The protection pipes have lengths of 6 – 12 metres and are welded together successively. You have to make sure of the roundness and a smooth surface of the pipe in order to keep the friction down.

An overcut or the application of pipe lubrication can reduce the pipe friction caused by forward thrust. In extreme cases, the friction forces and the jacking forces may lead to deformation of the pipe and stop the forward thrust.

In the starting pit, the thrust pipe is aligned exactly to the target and runs relatively stable in its direction, if no outer forces affect the steel pipe. Any occurring intercalations or hard layers lying diagonally to the thrust direction can divert the installation from the desired direction. The installation takes the course of the weakest resistance. Especially sliding upward makes it hard to keep the direction.

A larger bore diameter may be helpful because it maintains the exact position of the medium pipe which is going to be installed, the remaining annulus is filled in correspondingly. If the thrust pipe gets stuck, however, over-boring in counter-heading may help to complete the bore.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Conditions</th>
<th>Displaceability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed soil without groundwater</td>
<td>Loose settlement</td>
<td>Easy to displace</td>
</tr>
<tr>
<td>Mixed soil without groundwater</td>
<td>Tight settlement</td>
<td>Hard to displace</td>
</tr>
<tr>
<td>Water saturated mixed soils</td>
<td>The finer the grains are, the lower is the water porosity</td>
<td>Hard to displace without water drainage</td>
</tr>
<tr>
<td>Single grain soil</td>
<td>Tightest settlement</td>
<td>Can be displaced after grain particles have been shattered</td>
</tr>
<tr>
<td>Edgy grain shape</td>
<td></td>
<td>Hard to displace</td>
</tr>
<tr>
<td>Round grain shape</td>
<td></td>
<td>Displaceable</td>
</tr>
</tbody>
</table>

Table 1: Soil type classification
If nothing else helps, the thrust must be given up and filled back. A certain control of the bore path is possible when using a slanted drill pipe, which can be twisted by a hydraulic facility (hydraulic wrench) in the starting pit to turn the pipe into the desired direction. One-sided pressure application to the flexible thrust pipe is also possible (rudimentary articulation of the casing near the head activated by rods) with suitable steering presses. Because refractions are to be expected, a support with laser only makes sense if the auger flight has its own protection pipe.

The use of water for discharging the soil should be carried out by an experienced crew, or not at all. The risk of collapsing is very high, the stability of the roads or railway tracks which are being crossed, can no longer be guaranteed. Large amounts of water may flow out if a collapse like this happens beneath the river bed.

The pits are rather large because they have to accommodate the pipe length and the forward thrust facility; the finish may be elaborate, depending on the depth, perhaps it will need water-proof shoring or drainage. It also means a lot of work to remove the bore cuttings from the often rather deep pits.

Typical application ranges are diameters from 8 – 50 inches, larger diameters should be installed using the micro-tunnelling method because of the positional accuracy, smaller diameters are handled best with the displacement method. Bore lengths are approximately 250 ft; precision lies with +/- 1 percent of the driven length.

### 3.3.2 Ramming Method

The ramming method is an efficient, quickly accessible and feasible method for crossing streets, railway tracks and rivers. The pneumatically driven pipe ramming machines install open steel pipes as jacket or product pipes with diameters up to 4000 mm and lengths up to 80 m without pressing abutments, in soil formations up to class 5 (partially even through clastic rock), see Figure 9 and Figure 10.

The rammer, driven by compressed air, has a cylindrical shape with a cone for connecting add-on cones, cotter segments and/or soil removal cones or adapters which establish the tight-fitting connection between the machine and the pipe. Due to the two gaps in the soil removal cones or adapters, part of the tension of the spoil which is carried along, is released. The application of cotter segments prevents flaring up of the pipes and enables butt-welding of the single pipe lengths. The welding beads of spiral welded pipes have to be smoothed level with the pipe material in the area of the segment fitting depth in order to prevent point pressure.

The casing friction of the inner or outer pipe is reduced by cutting shoes creating a free-cut. Bentonite simplifies pipe installation by lubricating the pipe. Due to its very small displacement volume in the area around the cutting shoe, heave of the ground or street surface can be ruled out even for thin covers. This means, work can commence even from shallow pit depths.

Using a pneumatic lifting cushion, the rammer is precisely positioned axially behind the pipe and tightly fastened with straps. It is driven by a normal job site compressor. Due to the robust one-piece construction, an impact energy of 40000 kN can be achieved with the largest Tracto-Technik rammer at full capacity, which is passed on to the whole pipe string in an optimal way. The installation has an average speed of 15 m/h. After the ramming work is concluded, the pipe is emptied completely, using water pressure in combination with compressed air or water pressure alone - up to DN 500, this procedure is allowed with compressed air only, after the appropriate security measures have been taken care of. Larger pipe diameters call for manual soil removal with other auxiliary devices.

Typical for the ramming technique, next to all the general advantages of trenchless construction:

- simple, easy-to-transport equipment
- minimal job site set-up
- short equipping and propulsion times
- installation without elaborate abutments
- soil removal after the installation is completed
- relative aiming precision

Results of the advantages listed above and their consequent practical implementation: Due to the technical point of view, the Deutsche Bahn AG (German Railway Company) prefers this method to other crossing methods. And the Ruhrgas AG, a large German gas supplier, rates the method as recommendable.

### 3.3.3 Variations in Ramming Technology

The Ruhrgas AG has investigated the direct installation of product pipes on several job sites. The impact energy and its effects as well as the occurring stress...
of the thrust pipes was measured. The evaluation proved that it is unnecessary to add any additional design loads or precaution correction values to the calculation of the thrust pipes, the pipes are not damaged by this method. We come to the following conclusion: under consideration of certain constructional measures, this method is recommendable for pipe installation on a large scale. In order to go easy on the gas pipes, a reusable impact pipe should be placed between the product pipe and the horizontal rammer. Furthermore, care should be taken, not to impair lines or buildings in the neighbourhood by occurring vibrations.

Another variation of the ramming technique is the so-called slick boring. This technique utilises a horizontal rammer to drive home a protection pipe. After removing the soil, the medium pipe is connected. With a winch, an excavator or some other pulling facility, the bore pipe is pulled and then the product pipe takes its place (Figure 11).

Decisive assets are the advantages of the ramming method mentioned above, in connection with the reusability of the rammed pipes and the economical, direct, exact and gentle installation of coated pipeline pipes.

The pipe roofing method is another variety for crossing embankments. In this case, a protective roof and the contour for the intended multi-pipe tunnel is created by pipe-to-pipe ramming. After the excavated soil is removed and the site-mixed concrete vault is prepared, a passage for laying several lines has been created.

3.3.4 Microtunnelling

Microtunnelling is a trenchless method which is carried out as an unmanned pipe installation with fully automatic control. The jacking pipes are also the product pipes; depending on their function, they are mainly made of steel concrete, stone ware, glass-fibre reinforced concrete, cast iron or steel.

Microtunnelling is the further development of conventional pipe driving to a remotely controlled one. Originally it was developed for the unmanned, on-target driving for short distances of little more than 100 metres, but meanwhile it results in the already mentioned diameters and distances of several hundred metres. Typical driving lengths – without intermediate jacking stations – are between 100 and 250 metres. The maximal driving lengths to be achieved depend on the pipe type, bearable strain from the jacking propulsion forces, soil conditions, measures of possible friction reduction and the thrust capacity of the main jacks.

At the beginning, the term microtunnelling was used as the description of non-accessible pipe driving up to DN 800 / DN 900 in Germany; meanwhile, thanks to the further development of this technology, lines up to 4 metres in diameter can be driven with remote control. The largest possible pipe diameter to be transported along our streets is the upper limit of the diameter.

This development was made possible by the application of highly sensitive measuring instruments, the installation of reliable control devices and the adaptation of technologies used for excavating huge tunnel constructions with slurry and earth pressure balanced shields. It includes, among others, the exact detection of pressures, volumes, inclinations in the installation area and a precise control via computer-aided regulation and control facilities.

Microtunnelling was developed for the linear and exactly steerable course of the pipe path in height and position, these properties are specially required within the area of gravity lines, where often only a smooth inclination of the open channel are required and the sewer pipe is the installation pipe at the same time. Within the range of large diameters, curved drives are possible.

With the suitable choice of cutting tools a wide soil spectrum can be excavated; there are suitable working techniques from sand and gravel to rock. Decisive factor is the service life of the tools, which must be long enough to reach the target shaft or at least the next intermediate shaft. Long distance drives can be carried out by using intermediate jacking stations.

Furthermore, there is little settlement with this method. If handled properly, the pressure at the cutting face can be build up against standing soil and water pressure, the driven void is immediately secured by the thrust pipe. Bentonite is also used as a drilling fluid for this technique. Its task is to support the cutting face, lubricate the annulus between pipe and soil and transport the suspension charged with the cuttings.

Thus characteristic project parameters are the pipe diameter, driving length, topography, depth of the start and target shafts and the soil condition. With this method, even geologically difficult terrain can be bored over long distances.

The job site set-up consists of the pipe jacking equipment assembled in the starting shaft, a container with power unit and control container, settlement tank, recycling unit for the soil-slurry-suspension and a pipe storage. The set-up can be flexibly adapted to the available space on sites. The standard shaft is 3.20 m in diameter and can be used for driving pipes up to ND 800 with 2 m length; recovery of the unit makes a target shaft of 2.0 m in diameter necessary. If the jacking frame is turned around, it can also be used as a two-sided driving shaft. Larger pipe diameters require individual launch shafts, they are built for pipe lengths up to 3.5 m.
The installation of the jacking pipes is monitored by a laser beam from the prepared starting shaft. The operator in the control container traces the installation on the monitor. Steering motions are carried out by the control cylinders in the flexible bore head. A cutting wheel excavates the soil, supported by a slurry-water suspension. The suspension flows into the annulus between pipe and soil, reducing pipe friction; the outer walls of the following pipes are also frequently lubricated with Bentonite suspension by an automatic lubrication system to keep the friction low.

The suspension, mixed with the cuttings is pumped up by means of its own fluid circulation (supply and conveyor pipe) to a separation unit and, thus refreshed, returned to the conveying circulation, spoilt suspension is disposed.

Installation in ground water is possible without lowering, because the jacking thrust pipe leaves the shaft through a waterproof seal and enters the prepared target shaft in the same manner. The shafts themselves are established using a lowering technique with underwater excavation, a waterproof ground plate is also mounted (Figure 12).

The application of the microtunnel boring machines (MTBM) can be adapted to the geo-technical conditions; constructed as an earth pressure balanced or slurry machine it combines a large number of greatly differing bore heads. Almost any soil formation – finest loam, sand, gravel to rock - can be excavated.

Of course, exact knowledge of the geology and the groundwater conditions is necessary to carry out the installation successfully and without interruption. Important parameters are stability, particle size, water contents, plasticity, ground compactness, consistency and permeability.

In pipeline construction, the microtunneling method is suitable for crossing difficult terrain. Protection pipes are installed for the inserted product pipe. Establishing a so-called multipipe protection pipe for installing several single pipes could also be an option.

The longest installation of this kind ever heard of was the shore approach of the Statoil gas pipelines through the mudflats near Dornumer Siel. Reinforced concrete pipes were jacked beneath a dyke and into the tie-in chamber in the North Sea. This was a long distance heading with more than 2.8 km; the concrete pipe, which accommodates two 1000 mm gas lines, has an OD of 3.8 meters.

The advantages of microtunnelling can be seen within the area of protection pipe installation in urban regions with high-quality surfaces, in crossing difficult terrain with big covers, beneath high ground water levels and everywhere else, where restricted spaces does not admit large installation areas.

### 3.3.5 Horizontal Directional Drilling (HDD)

When talking about HDD technology, the first thought concerns the drilling of large diameters covering gigantic distances. However, the HDD technique is also suitable for short distances and pipes with just a few centimetres in diameter. Almost all pipe materials, particularly plastic pipes, but also steel, cast iron and asbestos cement pipes can be pulled in.

Besides pipelines for the transportation and distribution of fluid and gaseous media, meanwhile also irrigation and drainage lines, slope fortifications, contaminant detection, underground sanitation and the connection of offshore plants are accomplished by means of HDD.

But first of all, it is a method to install pipes underground – bypassing any kind of underground obstacles. Directional drilling is a construction method having less negative impact on environment and nature than any open-cut method. It is applied in cases, where any other known installation technique would be either impossible or only possible with a fairly great expenditure.

Like any other trenchless method, the diameter and length of the pipeline as well as the geology with its geo-technical effects play an important role. The drilling fluid has an important function – it is responsible for the support of the excavation, support and transportation of the soil, but also for reducing jacket friction when the pipe is pulled in. Just as important , of course, is the location and control of the drilling unit in order to perform the installation of the line in the intended path.

Corresponding to the complete range of diameters, lengths, materials and functions of the planned pipelines, drilling units of different sizes and capacities are available, and naturally also recommendations, rules and directions of the manufacturers, users, production engineers and contractors.

All kinds of different organisations – for example the national associations for trenchless techniques like the german GSTT and the ISTT as its international umbrella organisation, or DCA-Europe (Drilling Contractors Association) and its American sister organisation DCCA – are devoted to the task of drawing up guidelines and sharing experience amongst all persons concerned with the horizontal drilling technique.

#### 3.3.5.1 The Method

The HDD method installs hollow rods underground, using percussive rotational and pressure forces. The slanted bore head or a drill bit with a bent sub is mounted to the tip. Via the hollow rods which are bored in a shooting manner, a Bentonite suspension under pressure is carried to the tip of the drill; if rock boring heads are applied, this suspension is also used for driving the mud motors.

The so-called walk-over system is used as location system for the pilot bore; this is a transmitter (drill tip) – receiver combination (surface), working by means of electro-magnetism to locate the position of the bore head (Figure 13). Deviations are detected and corrected by a steering motion. The application range is only a few metres. For complex bores with existing disturbing influences, a separate magnetic field is build up. Larger units use the MWD principle (measurement while drilling); originally, it comes from the deep bore technique and transmits the data determined by the sensors lying directly behind the bore head back by cable.

The drilling fluid is a composition of water and Bentonite (a natural mineral)
and special additives, if required. It supports loosening and movement of the soil near the working face, reduces friction of the rods and the pipe when it is pulled in and transports the cuttings away through the bore hole. The suspension loaded with spoil is recycled and freshened up above the ground and returned to the fluid circulation once more.

The drilling fluid should fulfill its task even in permeable underground; additives improve the composition.

Normally drilling in ground water causes no problems. Still, the pressure and flow conditions should be watched closely in order to avoid uncontrolled diffusion. Components, like minerals (salts) and the nature of groundwater (pH-value) might affect the stability and function of the drilling fluid. As soon as the pilot bore has been established, the bore canal is upsized to the required diameter in one or more working steps with additional drilling fluid. Upsizing tools chosen to match the soil conditions are used; barrel reamers for soft formations, fly cutters for medium-hard soils and hole openers for hard rocky conditions. Forward reaming, for which the reaming tool is twisted forward from the side of the rig, using the pilot bore for guidance, is also popular.

On the rig side, the site set-up consists of the HDD rig itself, the power units, storing arrangements, a unit for mixing and recycling the drilling fluid as well as the control stand (Figure 14). On the pipe side, the pipe string is laid out, connected and brought to the installation place on suitable facilities (roller blocks, slide surfaces).

Drilling and pulling-in operations are continually carried out without interruption, if possible. When the bore is complete, its course is measured and recorded; then it is time for the required finishing works. The site is cleared, abutments of the HDD rig are removed, collecting pits are emptied, refilled and smoothed down, remains of the drilling fluid are disposed and the area is restored to its original or previously stipulated condition.

### 3.3.5.2 HDD – Machine Technique

The DCA provides 4 classes for HDD rigs (Table 2):

In each category, the bore rigs have different substructures, i.e. an under-carriage (rubber tracks, wheels) with own drive, a trailer or a steel frame mounted on supports; this is crucially decisive for the mobility on site, lifting capacity, size of the transportation unit and assembly and disassembly times.

The Grundodrill – Bore Rig 20 S manufactured by Tracto-Technik, for example, belongs to the midi class. With a pushing and pulling force of approximately 20 t, pipe diameters up to 600 mm and lengths up to 500 m can be pulled in. The built-in percussive hammer has a capacity of 280 kN of additional ramming force; allowing installation of the rods even in rocky soils. With this percussive unit, the application area of the rig is considerably larger than without. Special equipment for solid rock boring with a functional rock drilling engine is also available (Figure 15).

Recently a contract for a 450 t HDD mega-class unit has been awarded to Prime Drilling; it is intended for projects up to 2 km in length with pipe diameters up to 52".

#### Table 2: HDD rig classification

<table>
<thead>
<tr>
<th>HDD system Type</th>
<th>Max. pulling force (kN)</th>
<th>Max. torque (kNm)</th>
<th>Weight (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini</td>
<td>≤ 150</td>
<td>10 - 15</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Midi</td>
<td>150 - 400</td>
<td>15 - 30</td>
<td>10 - 25</td>
</tr>
<tr>
<td>Maxi</td>
<td>&gt; 400 - ≤ 2,500</td>
<td>30 - 100</td>
<td>25 - 60</td>
</tr>
<tr>
<td>Mega</td>
<td>&gt; 2,500</td>
<td>&gt;100</td>
<td>&gt; 60</td>
</tr>
</tbody>
</table>

![Fig. 13: HDD scheme: pilot bore, reaming bores, pipe pulling (Source: Tracto-Technik GmbH)](image13)

![Fig. 14: Rig side work space](image14)
3.3.5.3 HDD Projects - Basics
In order to guarantee the feasibility and success of a project, the client has to provide basics concerning the place of installation. One important point is the topography with site layout, view from the top, terrain profile and the depths of groundwater levels. These parameters give a first impression of the possible bore path, the distance to certain fixed spots and the best way to arrange the job site. The term geology includes historic surveys as well as viewing and evaluation of available documents which allow conclusions concerning existing buildings underground. Prospective drilling and sounding out give a good insight of the layers and composition of the soil; geo-physical investigations complement these results concerning the boundaries of layers.

The following laboratory tests and the interpretation of the results and findings, under consideration of the applicable drilling technique, should lead to a reliable statement in the ground expertise concerning the feasibility of the project in the building ground expertise. Further statements concerning external lines, buildings underground and climatologic and hydrographical conditions and their characteristics within the site should also be available.

3.3.5.4 HDD Projects – Project Conception
The basics of project conception [DCA], or the determination of the bore profile result from:
- entry and exit angles
- first and last bore section
- bending radii
- depth of coverage
- overcut factor

Detailed information concerning the points above can be found in the technical standards of the DCA or the DCCA; however, a few of the standard values are listed below:

The entry and exit angles should be between 6 and 15 degrees; smaller angles for larger pipe diameters, larger angles for smaller bending radii of the pipe.

The first and last bore sections should be straight and phase out without bending radius; 10 – 20 m for large bores and 5 m for smaller bores.

The type of load, drill rods or pipeline, has to be considered for the minimum bending radius; the bending radius of the upper bend must also be taken into account when pulling in.

Regard the different definitions for the depth of coverage. The 10 - 15 fold pipe diameter is recommended for offshore waters; due to the risk of blow-outs, values < 5 metres are critical. Country-relevant criteria concerning streets, landing runways and railway tracks must be maintained.

A factor of 1.2 (low-friction, stable underground) to 1.5 (unstable soil with caving-in tendency) is the approximate value for the relation pipe to bore diameter [DCA].

According to the DCA, the calculation of the required pulling force can be conducted according to the Netherlands Standard NEN 3651 or the American AGA method. The greatest pulling force makes an appearance at the end of the pulling process, when the whole pipe string is almost completely underground. When dimensioning the bore rig itself according to the pulling force, other operation conditions must also be considered; for example, starting out after longer standstill times during the pulling process, or when the bore hole has collapsed the required pulling force must be higher. The position of the pipeline in the bore hole can also compulsory powers, depending on lift or drift. Depending on the diameter and the geological underground, the factor 2 – 3 is recommended as the security correction value.

3.3.5.5 HDD Projects – Aspects of execution
Permissions concerning building rights, environmental rights and crossings should be known and available at an early stage. The content of this permission must correspond exactly with the chosen method, the applied technique and the time schedule. The contractor must procure the permissions concerning traffic rights (transportation, import and export regulations etc.), working rights (working times, holidays, exceptional permits etc.), environmental rights (water rights, withdrawal, discharge, disposal etc.) as well as the country-specific rights on his own accord.

Delivery and removal of the bore rig can be a great logistic achievement because of the distances and often limited accessibility to the job sites. This is also valid for delivering spare parts to the site; water should be available in the nearest vicinity, energy is generated by the corresponding diesel aggregates.

The right of way and access should be provided by the customer at an early stage; provision of the required area in sufficient size and condition is also important. A surface of 50 x 50 metres on the rig side is easily occupied, even without the drilling fluid pits; on the pipe side, the length of the stretch with working stripes for heavy machines on the side and the working surface at pulling point at the heading have to be maintained.

When pulling in the pipe, which is normally made of steel, ductile cast iron or HDPE, the effects of the material characteristics in the varying installation phases must be considered. Special care must be taken to protect the pipe and to avoid damage to cover, coating or lining. Consideration of the bending degree, maintaining the bending radius, laying out the pipe line during the pulling process and providing a stable and clear bore hole are further important factors.

A major aspect is the composition and recycling of the drilling fluid. The soil conditions determine the amount of Bentonite and possible additives. The quality of the drilling fluid plays a huge part in the success of the bore. The better the drilling fluid is adapted to the soil with regards to bearing capacity, gel structure, flowing properties, lubrication, filtrate value and swelling capacity the
For bores which require a large amount of large units. Bentonite is available in big packs for capacity must also be adequate. Collecting basin, separation and buffing free drilling action. The size of the fresh suspension is a must for friction-compatible; the permanent supply with rig and mixing and recycling unit must be compatible; the produced bore hole can be improved, swelling of the soil avoided and stickiness of the bore and the upsized bore hole is, not necessarily. The maximal drilling fluid volume consists of:

- volume of the bore (diameter x length)
- loss due to the filter cake
- loss due to precipitation
- volume of the mixing system

For a bore of 1,500 m length, 1066 mm steelpipe and a bore diameter of 1600 mm, this adds up to a volume of 4,000 m³ and some 100 tons of Bentonite, which continually has to be separated from the cuttings and completed again. The practical performance can be supported by software tools like the PD software „Drill Guard“, which is applied from the projecting stage on. Based on the data of fundamental investigation and planning, specific data of the HDD-rig, parameters of the pipeline and handicaps due to existing constraints, the ideal bore path is determined. The evaluation of the maximal pulling forces is helpful for choosing the most suitable HDD rig. The different operation conditions, caused by the alternating filling up of the pipe string while pulling, are also taken into consideration. Calculation of the hydraulic parameters determine the required fluid, amount of Bentonite and additive, flowing speed and soil discharge quantity during the single reaming operations.

These data are entered into a calculation program. The entry of dead lines and times for every single working step, of costs for machines and staff give the time limit and calculative values for the building process.

3.3.5.6 Performance - Shore Crossing

HDD belongs to the favoured installation techniques for pipelines in shore areas. The bore commences from the land side and into the sea. Entry and exit points of the bore are positioned to keep disruption of the surroundings as slight as possible.

In our example (Cliffhead Development Project) the job site is arranged approximately 400 metres behind the dunes; HDD drill rig, mixing, storage, pump and recycling unit, workshop and stem storage are accommodated on a surface of 50 x 50 metres (Figure 16).

On the sea side, the pilot bore emerges from the sea bed, approximately 600 metres away from the shore, in a water depth of around 6 m; the backreamer and, after the reaming processes, the medium pipe also, enter the bore hole from a swimming platform. Another popular method is to place the horizontal drill rig on a pontoon or a barge, in order to install the line in shallow water without trench and in great single lengths – diameter-dependent up to 2000 metres.

3.3.6 Combination of Drill and Ramming Technique

The co-operation between drill and ramming technique has secured the completion of a HDD bore several times before. The multiple applications are:

- driving an auxiliary tunnel
- supporting the pipe pull
- pulling the drill rods

When the auxiliary tunnel method is used, the formations which cannot be bored are holed through and the spoil is removed by an auger. The drill rods are pulled through the protection pipe and the HDD rig carries out the further bore, protected by the partial pipe work. A pilot bore running off course can also be “captured” from the target side. The protection pipe is rammed into the space created by the bore head tip, cleared again and then used as an auxiliary tunnel for the pilot bore to emerge in the direction of the target area (Figure 17).

With the support of the ramming technology Grundoram, many HDD bores have already been preserved from failure of the bore or the pipe pulling. The ramming machine is placed onto the drill rods or medium pipe during pipe pulling, and helps to keep the drill rods or the
3.4 Alternatives to HDD - Installation

Alternatives to the HDD technique are pipe driving techniques and crossings in open trenches; these may be performed in flowing water, after the stream has been by-passed (loop solution), or with barriers on one side and the help of a sheet piling box.

Lifting or floating the prepared pipe line siphon into position requires extensive preparations and elaborate equipment. It may even become necessary to build bridges for the reception of the pipeline. Usually alternatives, for example the bridge solutions, are less economical or even cause additional costs for service and maintenance.

It is also common knowledge that these methods cause disruption to the surroundings, and often mar their beauty permanently. A further aspect is the potential safety risk due to the influence of third parties.

4. Underground Pipe Driving Methods - Demands

4.1 Maintaining the International Standards

The regulations and the legal positions naturally are diverse. Political visions sometimes are able to enforce certain goals. Due to the practice of integrating international financial institutions like the world bank, IFC, EBRD etc. in transactions, certain regulating elements are considered. EBRD or IFC, for instance, have their guidelines for carrying out their own “due diligence” of a project. Besides the economical aspects, the financial backers also look out for the results and recommendations coming from the EIS – the Environmental Impact Statements (e. g. FERC) and the Environmental and Social Impact Assessments (ESIA) – see the example of the BTC project.

For the conception, construction, operation and maintenance of pipelines, the guidelines of the OPS (Office of Pipeline Safety), an organisation of the U.S. Department of Transportation, are valid in the United States. The Departments for Energy and Environment are also involved. Further parties involved in the approving process are the FERC (Federal Energy Regulatory Commission) or the national oil and gas institutions (API), or else they publish corresponding standards, like the ASCE – American Society of Civil Engineers. The DVGW – Deutsche Gesellschaft des Gas- und Wasserfaches – is one of the leading institutions of the European countries, which not only draws up the valid standards, but is also active in educating and qualifying the drilling and supervisory staff for pipeline installation.

In many countries of the world, there are guidelines for pipeline installation, which lean on the regulations of the OPS. In Europe, the large pipeline operating companies have their own installation rules. There is co-ordination within the international gas union and the national associations like the DVGW in Germany. Before concrete measures can be taken, a more or less intensive bureaucratic process, including the public, takes place in almost all cases. All public institutions which might be affected by the building measures are involved, from the highest national level down to any private association; maybe elsewhere the regional policy and compulsory approval proceedings are not quite as intensive as in Germany. Whether the project executing organization is the government or a company with private legal form, may also be crucial.

4.2 Bore Path Concept and Preparation/Building Ground Investigation

Planning of the intended bore path and calculation of the axis points can commence, as soon as ownership information relating to the path has been obtained and the right of way can be discussed.

The measurements accompanying the construction include staking out the path points, line measurement in the open trench, listing the welding seams and their presentation in cross-sections including the depth of coverage, they are used to document the new line installation.

Taking stock, considering the given topography and seeking information concerning existing lines in the bore path area are preparations for drawing up inventory records according to DIN 2425, DIN 18702 and supplementing regulations of the customer.

In distributing line construction, an overview building ground investigation for the stretch selected to accommodate the bore path is drawn up, no matter if the open-cut or the trenchless method is used. The investigation includes the search for karstic terrain, loam pockets to be avoided, roads with a high settling phenomenon, i.e. peat moor, mud, coarse clay, sea clay, limnic chalk etc., slippery zones or ground water deposits in the bore path. Now is also the time to clarify the depth of the average and top ground water level (maximal level of the ground water), the underground flow conditions and where to evade spring and fountain water collecting areas.

A course through mountain tracks may require additional slope securing measures, tunnel tracks or descending gradients may need additional detailed geo-technical investigations.

When crossing waters, the water regulations with the demanded minimum of coverage must be clarified, an investigation of the flow conditions, shoring and inclination of the banks is also important. All regulations relevant for the protection of forest and nature must be heeded in forest regions, the depth of the roots of the largest trees also requires investigation. Possible
compensation areas within the accompanying space around the pipe line path for inevitable impairment of the natural balance must be included in the plans.

Already existing lines in the path area are handled in a similar way. Previously installed utility lines require a certain distance to the new line; co-ordination with the operator line owner is necessary. Access roads to the bore path and driving possibilities on site have to be considered, also the space for pipe storage, mass balance, assembly and disassembly of the machines; final check paths, landscaping and access to compressing and monitoring stations are included in the plan.

4.3 Pre-Conditions for Final Checks
The more detailed determination of the bore path course should also include the possibility for constant pipeline check. Helicopter landing and constant pipeline checks should be possible. Also, the preconditions for installing parallel data lines and control cables, i.e. for the operation and control of the stations, should be given from the beginning.

5.1 Comparative Reflections on Construction Methods
When comparing different construction methods, the first aspect is always the financial one, namely the direct costs. Indirect costs which are generated by the impact of humans, nature and environment are often ignored. The emission of dust, noise and exhaust gas during the complete working time is the first great disturbance factor.

These costs are not economically interesting for a project, but the effects on the complete commercial life must not be swept under the carpet; they toggle mobility, cause delays, lead to loss in sales, reduce productivity or even endangering the earnings for a living. All over the world, there are still regions with inhabitants who depend completely on an intact natural environment. For farmers in barren regions, the maintenance or unrestricted utilisation of their few fertile fields is vital; fishermen rely on their intact fishing grounds.

A further aspect are consequential costs due to the work itself, which often occur when operations are not carried out correctly. Who is charged with the costs for overhauling works on street surfaces, who pays for subsequent treatment due to settlement of unprofessional backfilling, when the guarantee periods have run out and the enterprises can no longer be made liable for damage.

The open-cut construction method causes consequential costs, because normally stable soil formations are disturbed by the building measures, damaged slopes start moving, erosions lead to earth movements, surfaces without vegetation are generated. Consequential costs due to the breakage of pipelines already in operation are hard to calculate.

Consequential costs are also caused by line operation: the Peace River was crossed by a HDD bore of 3600 ft (1039 m) in length and 36-in in diameter to install the Alliance Gas Pipeline - the difficulty degree was generally acknowledged; as a back-up option in case of a failure of the HDD bore, an elaborate and extremely expensive suspension bridge (two pylons, main spanning width 480 m, width of the two side spannings 245 m each ) for the reception of the pipeline was planned, paired off with the costs for maintenance and servicing for many years.

When confronted with the decision for an installation using the open-cut or trenchless method, we must not compare the costs alone, sometimes it is also a question of building culture. Is it intuitively come to the immediate conclusion, that the trenchless construction method prevents many of the previously discussed disadvantages right from the start, also before commissioning the pipelines. Let us not forget the fact, that often there is no alternative to trenchless installation.

5.2 Economical Aspects
The crucial question, which method is more economical, often has no simple answer. There are too many individual building projects, the marginal conditions are manifold.

Basically, drawing a comparison between the different methods and their costs for construction only makes sense for a concrete project. Still the few extensive examinations and attempts to make the costs more transparent by evaluating documents and numerals are well appreciated. Without going into details or trying to evaluate the method, the results of such examinations shall be summarized in the following.

One example is the examination carried out by NRC – the National Research Council in Canada. This examination from June 2002 is based on 174 projects; they all are projects of different lengths and diameters, carried out with different construction methods. In reference to the average costs per mm in diameter and metre in length of all projects, the relations of the costs for HDD to pipe jacking to micro-tunnelling are 1 : 1.44 : 3.2; compared with open trench methods, the costs for the projects which have been carried out using the HDD technique lie 23% below the costs for open trench methods. When only diameters were compared, the trenchless projects up to 940 mm were also always cheaper, but above 960 mm, some open trench projects were more economical.

The Final Report of the King County Project also shows the cost advantages of the HDD – technique clearly, when compared to microtunnelling. When single projects are compared, we come to the conclusion, that the HDD method dominates the installation of pressure and gradient lines, because the precision of position and height is not so important for these lines. But don’t forget there are also the consequential charges and long-lasting life cycle costs.

Trenchless Technologies have proved...
their value in practice; the methods are up to the technical standard and have showed their economic advantages. In order to apply these techniques successfully, their potentials but also their limits have to be examined carefully for every new project.

5.3 A Contribution to the Availability of Energy

Beside transportation by ship, pipelines assure the supply for the consumer. Trenchless techniques play a big part in pipeline construction; often they are the focus of attention. They allow the installation of paths in topographic, geotechnical or technical conditions which would make open-cut installation impossible.

The economic aspect must not be forgotten – this installation method can actually save money while construction and under operation. An determined bore path is often only possible because of trenchless installation, detours are avoided, time and money consuming discussions are prevented, the utilisation of soil and grounds is only interrupted for the residents in certain spots or not at all – expenditure for compensation is reduced.

Trenchless Technologies help to make pipeline installation more profitable and enable the safe and economic supply for the consumer. A high-quality underground installation hardly disturbs the building ground stability, thus preventing breakage and damage to the pipelines and making their operation relatively safe. Consequential damage of the surface or the environment is almost unlikely.

But not only large transportation pipelines are important, further distribution networks are required for urban regions and cities. With growing population, especially in urban regions, trenchless technologies become essential for installing lines for gas, water and other media quickly, economically and safely.