

Horizontal Directional Drilling

DCA Technical Guidelines

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Information and Recommendations
for the Planning, Construction and Documentation of
HDD - Projects



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1 Foreword

Five years after the founding of DCA and after the initial years of successfully setting up the association the extensively revised 2nd edition of the Technical Guidelines of DCA for the controlled horizontal drilling process (Horizontal Directional Drilling, HDD) was published. This was at the beginning of the new Millennium and is based on practical experiences as well as the latest scientific knowledge.

The revised edition should contribute to a further increase in the quality of planning and construction of HDD-Projects, thereby promoting the lasting acceptance of this contemporary special construction technique. The present Technical Guidelines of the DCA will provide fundamental information for planning, execution and documentation of HDD-Projects to not only builders and contractors but also to the specialist companies carrying out the work.

The new Technical Guidelines of the DCA have been developed in close cooperation with the American sister association Drilling Crossing Contractors Association (DCCA) as well as many, well-known international experts. The DCA-Board takes the liberty and opportunity to thank all contributors for their cooperative and constructive teamwork.

Aachen, Spring 2001

Drilling Contractors Association, (DCA-Europe)

2 Project principles

To assessing the feasibility of a HDD-project various basic documentaion, normally distributed by the Client, is needed. In particular the documentation relating to the topography and the geology of the project location is of paramount importance. All specific additional information, essential for the project, shall be incorporated in the final assessment. The documentation below is one by one a pre-requisite for the evaluation, planning and execution of HDD- Projects.

2.1 Topography

For the evaluation and assessment of the conditions at groundlevel the required documentation along the planned route shall consist of:

- **Location plan**
- **Top view**
- **Longitudinal sections including levels**
- **Depths of streams and rivers**

➤ **Location plan**

To determining the rig site, pipe site, pipe storage area, pipeline assembly area and other construction site facilities suitable location plans and topographic charts in the scale of 1 : 500 up to 1 : 25 000, are helpful.

➤ **Top view**

To effect of important geometric information of the planned drilling, such as the envisaged drilling length, the distance to nearby buildings, the width of structures to be drilled underneath etc., requires a reliable and complete detail plan (e.g. at a scale of 1 : 1000). To benefit future detailed planning and documentation it is advised to relate the essential information in the plans to Ordnance Datum or any other relevant (national) survey grid.

➤ **Longitudinal sections including levels**

To determine a drilling profile information about the ground levels along the planned route are necessary. In designing the drilling profile the distances to particular areas and possible obstacles can be taken into account. To benefit future detailed planning and documentation it is advised to relate the essential information in the longitudinal sections to Ordnance Datum or any other relevant (national) survey grid.

➤ **Depths of streams and rivers**

If case the planned drilling underpasses a stream or river a depth sounding or series of depth soundings shall be carried out to determine the level of the bed of stream or river. Only in this way a safe distance can be designed and kept with regard to bed level and level of borehole. Especially deep streams or rivers may have a considerable influence in the detail design (e.g. local bed erosion).

2.2 Geology

Prior to the execution of the horizontal directional drilling technique proper and comprehensive soil investigations along the planned drilling route shall be carried out and reviewed in order to assess the feasibility of the project and reduce the construction risks to a minimum. The Employer shall carry out the required soil investigations to obtain all the necessary information.

The programme of the necessary investigation, the professional monitoring of site- and laboratory activities and the drafting of the soil investigation report shall be carried out by a geology advisor / geologist of an approved and reputable geology consultancy. The geologist must have experience in similar projects and must hold relevant knowledge of the working methods and particular details of the HDD technique

The scope of the geotechnical investigations depends on the local geological conditions and the key data of the planned project. In general the soil investigations shall comprise the following elements:

- **Classification and Evaluation of existing documents**
- **Historical research**
- **Boreholes**
- **Penetration tests**
- **Geophysical investigations**
- **Laboratory tests**
- **Geotechnical report**

In common soil conditions, i.e. not particular complex subsoil conditions, recommendations on the soil investigations are mentioned below. When uncommon geological conditions or more complicated soil structures are present a more extensive soil investigation is generally necessary.

➤ **Classification and Evaluation of existing documents**

The classification and evaluation of existing soil data shall be examined. Available maps and materials are to be studied (geological maps, sections, bore logs, profiles etc.). Insofar as practically suitable geotechnical investigations made available from previously constructed projects (bridges etc.) which are in the vicinity of the planned project can be used and may reduce the scope of the soil investigations.

➤ **Historical research**

Historical research in the vicinity of a planned HDD-Project shall be carried out particularly near industrial areas, former settlements and abandoned constructions. Apart from the examination of existing archive material (maps, old plans, aerial photos etc.) a site visit is an (professional) obligation.

➔ Boreholes

To determine the soil layers and the required characteristic soil properties boreholes shall be made. Cylindrical bore holes are to be carried out for undisturbed core recovery at 50-100 metres interval, in alternating order at 5 metres next to the centreline of the planned drilling trajectory. One shall adhere strictly to the intervals for the boreholes, especially in the presence of waterways. Information about the ground conditions immediately under the bottom of the river is of great importance and determines the success of the construction method.

The boreholes can be classified in:

- Rotary core drilling
- Ram boring
- Percussion boring

With regard to the borehole sampling the commonly used methods are:

- Method providing continuous recovery of core samples
- Method providing continuous recovery of non-cored samples
- Method providing incomplete soil samples

Reference is made to more detailed information in BS 5930 or other applicable National or European Standards or Codes of practice about soil - or site investigations.

The Standard or Code to be used shall be selected in close cooperation with the nominated or appointed geology consultant. In most cases it is important to select an adequately large borehole, to ascertain that the coarser fractions (gravel, stones etc.) are detected.

The depth of the borehole shall be 2 to 5 metres below the (invert) level of the planned drilling profile. Changes can be confidently processed to the drilling trajectory in the case of obstacles encountered during the drilling process. Boreholes shall be properly filled and restored, e.g. with expanding clay pellets, to prevent a mud outbreak.

➡ Penetration tests

To determine the important soil parameters, e.g. compactness etc., or to identify the boundaries within the stratum structure, the following penetration tests can be used:

- Cone Penetration Test (CPT)
- Standard Penetration Test (SPT)

The CPT method pushes a cone at the end of a series of rods into the ground at a constant rate and measurements are recorded of the total combined resistance, the sleeve friction and the cone resistance.

The SPT method drives with constant impact energy a probe into the ground. The required number of blows per unit length penetration is each time recorded. The SPT method differentiates between light, medium and heavy ram probes.

The cone penetration tests are to be planned in the vicinity of the boreholes and if necessary at intervals in between. The depth of the cone penetration tests shall be the same as for the boreholes thus enabling a comparison of the derived soil parameters in the various strata.

All cone penetration tests shall be properly filled and restored, e.g. with expanding clay pellets, to prevent a mud outbreak.

➡ Geophysical investigations

The type and extent of the geophysical investigations to be carried out depend on the geological conditions recorded from the examined boreholes and penetrations tests as well as the local conditions that could have influenced the method and results. Take into account e.g. conditions at ground level, area utilization and effects from the surroundings. The geophysical procedures selected for the investigations can be executed from the land or from the water.

In view of the horizontal directional drilling technique the following procedures can be applied notably:

- Electro Magnetic Reflection (EMR, or „Georadar“)
- Geoelectric
- Seismic

Electromagnetic reflection (EMR, „Georadar“) is particularly suitable in determining the layer boundaries. Short electromagnetic pulses are emitted into the soil from a source that is placed on ground level. The electromagnetic waves are reflected inter alia at the layer boundaries and recorded by receivers on ground level. The duration and amplitudes of the reflections of the impulses are measured and recorded.

The application of geoelectrical measuring methods can also assist in determining the layer structure in the subsoil. It is assumed that the various layers with their respective electric resistance distinguish sufficiently to take measurements. When applying geoelectrical measuring a row of probes and electrodes are placed in a straight line in the subsoil. The electrodes are placed outside, the probes are inside. Subsequently an electrical current is led into the subsoil by the electrodes whereby the probes register the electrical voltage. The apparent resistance can be calculated from the measured current and voltage for each individual layer. Conclusions can be drawn about the layer structuring by comparison using reference data.

Seismic measuring methods are to a certain extent similar to the EMR method. Where EMR uses electromagnetic pulses, seismic measuring uses sound waves. Receivers (geo-phones) record the reflections of the sound waves, emitted to the subsoil. Ground layers and layer boundaries can be distinguished with this method provided the layers have sharp transitions in porosity, density, etc..

➞ **Laboratory tests**

The samples obtained in the site investigations will be laboratory tested. As a minimum the tests for non-cohesive, unconsolidated soils can be:

- Particle size / - distribution
- Particle shape
- Void ratio
- Relative density
- Compaction ratio
- Permeability

For the examined soil layers and for cohesive soils:

- Structural shape / appearance
- Liquid and plastic (Atterberg) limits

Additional tests may be necessary to investigate specific conditions, e.g. swelling of clay. In the case of rock (the presence of discontinuities and cavities, and the effects of weathering are likely to have a great influence on engineering behaviour) the tests below as a minimum apply:

- Rock structure (bedding / fissures)
- State of weathering
- Tensile strength
- Compressive strength

In addition reference is made to more detailed information in BS 5930 or other applicable National and European Standard or Code of Practice about soil - or site investigations.

➞ **Geotechnical report**

The results of the site investigations are to be compiled by a geology consultant in a geotechnical report. The report shall contain the specific soil characteristics in relation to the use of the horizontal directional drilling technique. The geotechnical report shall enable the qualified Engineer or Contractor to assess the feasibility of drilling through the ground layers to be encountered.

The soil layers within the planned drilling trajectory shall not only be described in writing but also be presented in a geology section. In this geological section the borehole logs and CPT/SPT information can be incorporated together with their locations and geo-physical information. The results of the geophysical tests as well as historical data shall be indicated on the section. The geological section shall not be made in an exaggerated or distorted scale. When the presence of geological or man-made obstructions/abnormalities are known, e.g. coarse gravel, boulders, rock fragments, foundations, soil improvements, cavities, pollution, etc. the information shall be indicated in the geological section.

It is recommended to use the National or European approved classification and terminology when describing the examined soil layers.

2.3 Miscellaneous

Depending on the HDD project particulars, additional data can be required to evaluate the feasibility of the project, e.g.:

- **Artesian water or aquifers**
- **Existing cables, pipes, ducts etc.**
- **Foundations/basements/caves**
- **Climate and Hydrographical data**

➤ **Artesian water or aquifers**

Part of the overall survey of the sub-soil is the investigation of artesian water or aquifers. Knowledge about the waterpressures that can be encountered during the execution of a HDD project is essential. The investigation about deviations to the hydrostatic waterpressure shall be part of the general soil investigations.

➤ **Existing cables, pipes, ducts etc.**

If there are existing cables, pipes, ducts etc. situated near the crossing, their exact positions, as well as their specifications and the medium conveyed is to be determined and stated. Existing cables, pipes, ducts etc. are relevant to the HDD-project, if they will either be intersected by the horizontal projected drilling or if they run parallel at a distance of less than about 20 m.

➔ **Foundations/basements/caves**

If civil engineering works are present near the crossing or remnants of such in the form of old tunnels, foundations or other construction works, then their exact locations and dimensions are to be determined and identified. Safe distances to sheetpiling and piles, retaining walls etc. are to be maintained.

➔ **Climate and Hydrographical data**

Depending upon the region in which the horizontal directional drilling technique is to be carried out, climate data such as rainfall distribution and quantity, as well as temperature information (fluctuation bands, absolute values) can also be important. The same goes for hydro-graphical data, e.g. current conditions, tidal range etc.. Also details about water quality, e.g. pH-values, salinity etc., are often needed, if the river, stream, canal or ground water is to be used for preparing the drilling fluid.

3 Authorisations

3.1 Contractor

It is the contractor's responsibility to obtain certain country-specific authorisations, e.g.:

- **Rights of Way authorisations**
- **Employment authorisations**
- **Environmental authorisations**
- **Miscellaneous**

➤ **Rights of Way authorisations**

- Transportation, including amongst other things the transport, removal and transfer of plant, machinery equipment to, from and on the construction site.
- The regulation of traffic, e.g. setting - road blocks, carriageway restrictions, speed limitations etc.

➤ **Employment authorisations**

- Working time permits with regard to overtime, night work, sunday and holiday work.

➤ **Environmental authorisations**

- Water-extraction licenses for the withdrawal of water from streams, rivers, canals or groundwater/wells for the preparation of drilling fluid as well as for, if required, providing necessary ballast for the product pipe.
- Water-extraction licenses for the required decreasing of the ground waterlevel through the installation of dewatering or deepwells and the discharging of the groundwater into a nearby stream, river or canal.
- Recycling of drilling fluid and removal of drill cuttings to a licenced disposal area.

➤ **Miscellaneous**

- In addition to the authorisations already mentioned, there may be special regulations in individual European countries that must be taken into account during the planning of an HDD- Project.

3.2 Client

It is the responsibility of the client to obtain various country-specific authorisations, including but not limited to:

- ➔ **Construction authorisations**
- ➔ **Utilisation authorisations**
- ➔ **Environmental authorisations**

➔ **Construction authorisations**

- General building authorisations
- River, navigation and police authorisations

➔ **Utilisation authorisations**

- Use and occupation contracts with owners of all real estate
- Entry permits, including but not limited to the permits for driving on or over private property, building site installations, pipe storage and stringing site(s) and working areas etc.
- Provision of areas for the establishment and operation of storage reservoirs for the drilling return fluid etc.
- Permits for crossing dikes, railway lines, roads, rivers, streams and canals etc.

➔ **Environmental authorisations**

- Agreement with the appropriate special authorities regarding the recultivation of areas at the time of cleaning up the constructions site.
- Agreement with the appropriate special authorities, from an ecological viewpoint, regarding, noise abatement, restriction on construction times and the protection of landscape areas and wildlife etc..

4 Project planning

4.1 Fundamentals

An essential element of the project planning of horizontal drillings is the establishment of the drilling profile between entry- and exit point. Thereby various framework conditions must be observed in order to ensure, that the intended theoretical drilling profile line can also be realised in practice. The following fundamentals to be particularly observed are:

- ➔ **Entry- and Exit angle**
- ➔ **Slant tangential sections**
- ➔ **Radii of curvature**
- ➔ **Cover**
- ➔ **Hole Diameter**

➔ **Entry- and Exit angle**

The entry- and exit angle of horizontal drillings should be related to the bending radius of the pipeline to be installed and should lie between about 6° and 15°. Thereby it is regarded as a rule in general, that this angle should be flatter the greater the diameter of the pipeline.

The entry angle can be steeper if personnel are not required to work on the drilling rig (smaller drilling installation). The exit angle can be steeper if pipes have a smaller bending radii (e.g. PE-pipes) resulting in a smaller overbend („cat back“) at the exit point.

➔ **Slant tangential sections**

In the first or last drilling sections the provision of a drilling radius in the drilling profile should be avoided, since these drilled sections near the surface are often not suitable (less compactness etc.), to realise a prescribed, curved profile with the drill head.

The length of these straight sections varies with the bored hole dimensions and the weight as well as the rigidity of the bottom hole assembly (BHA). The larger the drilled hole and the heavier and stiffer the bottom hole assembly, the longer the straight sections should be.

As a guide for large bored holes a value of 10 - 20 m can be applied, whereas for smaller bored holes this length can be shortened to about 5 m.

➔ Radii of curvature

When designing the drilling profile, the minimum permissible radius of curvature plays a decisive part. Differentiation must be made between the minimum permissible curvature radius (minimal permissible bending radius) of the drilling rods and the minimum permissible curvature radius of the pipeline to be installed.

As a rule, the minimum radius relevant to the planning of small drillings and PE-pipes is governed by the corresponding radius of the drilling rods. Larger drillings and steel pipes, are governed by the minimum radius of the pipeline to be installed.

If the drilling rods dictate the minimum radius, then the drilling profile is easy to determine by using the recommended values provided by the manufacturer. As a guide radii between 30 and 250 m can be assumed.

If the minimum radius is to be dictated by the pipeline to be installed then the determination of a curvature radius relevant for planning and execution is more laborious. Here, a further differentiation between the actual drilled hole and the overbend („cat back“) on the surface can be made.

In general the elastic line according to Mohr is valid for the radius
(cf. Dubbel, 12th Edition):

$$R_{min} = \frac{E \cdot D_o}{2 \cdot \sigma_{all.b}} = R_{elast}$$

R_{min} = minimum permissible bending radius [m]

E = modulus of elasticity [N / mm²] = $2,06 \cdot 10^5$ [N / mm²]

D_o = pipe outer diameter [m]

$\sigma_{all.b}$ = permissible bending stress [N / mm²] = $\sigma_{all.} - \sigma_t$

R_{elast} = elastic bending radius [m]

Drilled hole

For a pipe with internal pressure, by implicitly taking the internal pressure ($\sigma_t = \sigma_{all.} / 2$) into account the following equation for the minimum bending radius results:

$$R_{min} = \frac{E \cdot D_o}{\sigma_{all.}}$$

R_{min} = minimum permissible bending radius [m]

E = modulus of elasticity [N / mm²] = 2,06 · 10⁵ [N / mm²]

D_o = pipe outer diameter [m]

$\sigma_{all.}$ = permissible stress [N / mm²]

σ_t = tangential stress [N / mm²]

With a weld seam quality assessment of $V_N = 1$ then

$$\sigma_{all.} = K / S$$

Accordingly, the permissible limit value of the minimum permissible bending radius for pipelines made of steel (cf. DVGW-worksheet G 463) is defined as follows:

$$R_{min} = 206 \cdot \frac{S}{K} \cdot D_o$$

R_{min} = minimum permissible bending radius [m]

S = safety factor [–]

K = minimum yield point [N / mm²]

D_o = pipe outer diameter [m]

For drill-technical reasons, this calculation formula should only be applied for pipes with nominal diameters < DN 400.

In conformity with the final report of the HDD working group of the Ruhrgas AG (Germany) from 1996, it is recommended that the following calculation formulae are applied for larger nominal diameters:

Pipe nominal diameter	Calculation formula
$\geq DN\ 400 \leq DN\ 700$	$R_{min} = 1400 \cdot \sqrt{D_o^3}$
$> DN\ 700 \leq DN\ 1200$	$R_{min} = 1250 \cdot \sqrt{D_o^3}$

Note: above formula are not similary interpreted in all countries.

R_{min} = minimum permissible bending radius [m]

D_o = pipe outer diameter [m]

The bending radii thus determined should in all cases be larger or as large as those that would result from the calculation methods according to DVGW-worksheet G 463.

Overbend („cat back“)

When pulling the pipeline string into the drilled hole, the pipeline string describes a curve into the drilled hole prior to the transition into a straight pipeline section, generally known as the overbend. Since the pressure in the overbend is zero (when the pulling operation takes place) the safety correction value can be reduced to $S = 1.3$, and the minimum radius of the overbend during the pull-back process can be given by the corresponding substitution of the generally valid equation according to Mohr as follows:

$$R_{min} = 134 \cdot \frac{D_o}{K}$$

R_{min} = minimum permissible bending radius [m]

D_o = pipe outer diameter [mm]

K = minimum yield point [N / mm²]

For practical reasons however (stiffness of the pipeline) - especially for large pipe diameters - a larger radius in the overbend should be chosen.

As reference value, a radius can be assumed, the value of which equals in metres 0,8-times the diameter of the pipeline in millimetres, e.g.:

Pipe diameter = 800 mm → Radius of upperbend ≈ 640 m

The facts described regarding the differing curvature radii in the drilled hole as well as near the upperbend are graphically illustrated in Fig. 4.1.

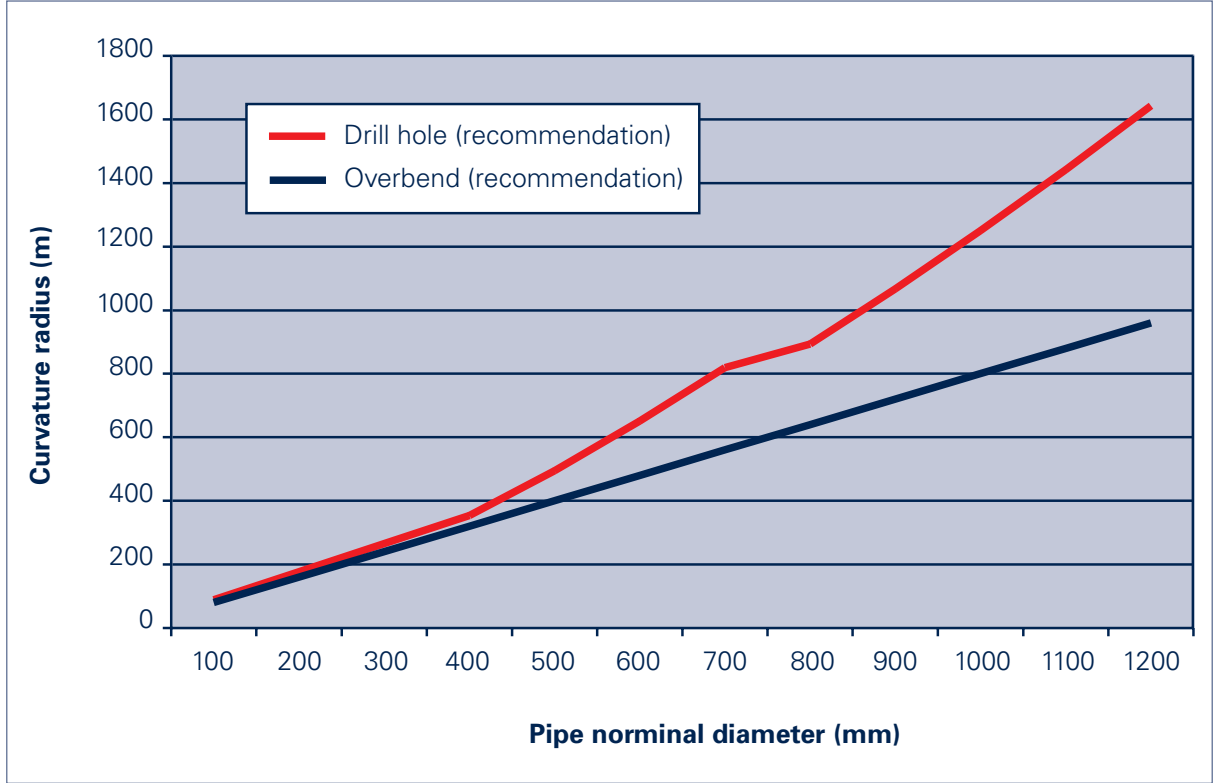


Fig. 4.1: Curvature radii for steel pipelines

Combined Radii

The preceeding comments refer to radii which are in the vertical plane only, some drilling projects however require a combination of curves in two planes, for example a curve in the verticle elevation as well as in the plan view. Combined calculated radii will always result in a smaller radius compared to a single plane curve.

The preceeding information shows how to derive to the minimum permissible radii for the pipe. The combined borehole radius is calculated by using the following formula:

$$R_{combined} = \sqrt{\frac{R_h^2 \cdot R_v^2}{R_h^2 + R_v^2}}$$

$R_{combined}$	= <i>Combined Radius</i>	[m]
R_h	= <i>Horizontal Radius</i>	[m]
R_v	= <i>Vertical Radius</i>	[m]

➔ Cover

The distance between the top of the pipe and the surface or riverbed is called the cover. Quite often and for simplicity, the distance between drill axis and surface or riverbed is alternatively refered to as cover.

Cover requirements under lakes or rivers for drilled pipelines should equal 10 to 15-times the pipeline diameter. For example when laying an 800mm diameter pipeline, the cover in water areas should be 8 to 12 m. For smaller pipes cover should not be less than 5 metres however the cover should be assessed critically with regard to the danger of drilling fluid breakouts.

Similar values of cover should be adhered to for main roads, runways and other obstacles to be crossed. For rail crossings there are additional national regulations and specific information and approvals should be sought in the appropriate country. The greater the chosen cover, the less chance there will be of break outs and the occurrence of underground collapses.

➔ Hole Diameter

The ratio between the drilled hole and the pipe diameter is important. The largest pipe diameter is thereby regarded to be relevant (as a rule in the jointing area). A suitable ratio will contribute to a smooth pullback of the product pipe into the prepared drilled hole.

The following ratios, from experience, have proven to be reliable:

- from $1.2 \times D_o$ to $1.5 \times D_o$

depending on the soils.

4.2 Drawings

The following graphic illustrations are necessary for the planning of projects using the horizontal directional drilling technique:

- ➔ Longitudinal section
- ➔ Plan view
- ➔ Cross-section(s)

For larger drillings the following additional drawings are recommended:

- ➔ Site layout plans (Rig- and Pipe site)
- ➔ Overbend and pipeline stringing area (rollers)

➔ Longitudinal section

The longitudinal section drawing of a horizontal drilling should contain, at least, the following details:

- Groundwater level
- Ground profile and levels along the crossing length with the dimensioning of important points, related to a suitable coordinate system
- Water level and profile of the riverbed, with tidal range, details about low-water level and high-water level
- Entry and exit angle of the drilling
- Drill profile with dimensioning of the same, e.g. chainage and levels
- Details of the vertical curvature radii for each section

- Details of combined radii for each section
- Details about the horizontal length of the drilling and the total length of the drilling
- Dimension of cover in critical areas, e.g. under lakes or rivers, at entry point etc.
- Illustrations of the positions and the penetration depth of exploratory drillings and soundings as well as details about the drilled ground layers
- Illustration of known obstructions, e.g. existing pipelines, foundations, retaining walls etc.

➔ **Plan view**

The plan view drawing of a horizontal drilling should at least contain the following details:

- Illustration of the topography up to a lateral distance of about 5 to 20 m in relation to the drilling axis
- Coordinates of entry - and exit points of the drilling, related to a suitable coordinate system
- Route of the drilling axis with dimensioning of same, e.g. every 10 m
- Details about the horizontal radii for each section
- Illustration of the position of soundings and exploratory drillings (soil information)
- Illustration of known obstructions, e.g. existing pipelines, foundations, sheet piles etc.
- Intended working areas of the Rig site and Pipe site
- Geographic north

➔ **Cross-section(s)**

The cross-section drawing of a horizontal drilling should contain at least the following details:

- Drilled hole diameter
- Pipe cross-section(s) with details type of pipe material, wall thickness, type of coating, any other protections and if applicable details of the lining.

➤ **Site layout plans (Rig site and Pipe site)**

The site layout plans for a horizontal directional drilling should contain at least the following details:

- Position and size of essential components of a horizontal drilling system, such as the drilling rig, control cabin, energy supply etc.
- Type and method of anchoring the drilling rig
- Position and size of the mud pit(s)
- Location of storage areas / crane area
- Drive ways

➤ **Overbend and pipeline stringing area (rollers)**

The overbend and pipeline stringing area (rollers) drawings should contain at least the following details:

- Position and distance of the roller supports in side view and if necessary top view
- Radius of overbend
- Maximum height of overbend
- Details of roller substructure
- Access roads

4.3 Design/Calculations

A further element in the planning of a horizontal drilling is the preparation of important calculations. Hereby one can basically differentiate between the following conditions:

- **Construction conditions – pipeline under construction**
- **Operational conditions – Serviceability Limit State**

In general those calculations concerning the construction conditions are the responsibility of the contractor, while those calculations concerning the operational conditions are generally the responsibility of the client.

➔ Construction conditions - pipeline under construction

When laying a pipeline utilising horizontal directional drilling technology the following two aspects are to be particularly observed:

- Are the stresses induced to the pipeline by the pullback operation within the permissible stress levels?
- Will the rig and equipment be able to provide sufficient forces necessary for the pipeline installation?

To answer both questions, the maximum expected pull force during the pull back operation must be determined. Differentiation should be noted between the pull forces required directly at the pull head in order to overcome the frictional forces on the pipeline, and the pull forces the drilling system must deliver. The latter are in all cases higher, since they must overcome additional frictional forces resulting from the drill string, the reamer and the swivel.

Pull force at the pull head

During the prevailing part of the pull back operation a section of the pipeline is already in the drilled hole, whilst the rest of the section is still on the roller-track outside the drilled hole.

The force needed to overcome the friction on the roller-track is, dependent upon:

- Weight of the pipeline including coating, casing, lining and ballast system
- Type and geometry of the rollers
- Radius of the overbend
- Length of the pipeline on the roller supports
- Condition of roller supports (lubrication etc.)
- Coefficient of friction of roller bearings

The forces needed to overcome the friction in the drilled hole are dependent upon:

- Friction between pipeline surface and drill fluid
- Friction between pipeline surface and drilled hole „wall“

The friction between pipeline surface and drill fluid depends mainly on the type of coating as well as on the fluid parameters such as density, viscosity, cuttings suspended in the fluid and the fluid flow velocity in the annulus between pipeline and drilled hole „wall“

The friction between pipeline surface and drilled hole „wall“ is particularly affected by parameters of the ground (friction coefficient), the resulting positive or negative ballasting of the pipeline in the drilled hole and the overall geometry of the drilled hole (curvature radii).

Pull force on the drilling rig

The forces the drilling rig must deliver are higher than those forces occurring at the pull head, because it must pull the pipe plus the drill string.

The magnitude of the frictional forces occurring depends upon the technical parameters of rig and auxiliary equipment (formation of tool joints, weight of the drilling rods, formation and weight of the components of the pulling assembly etc.). In addition however, just as with the previously mentioned frictional components of the pipeline, the geometry of the drilled hole plays a considerable part in the friction occurring on the drill rods. The larger the drilled hole radii and the „smoother“ and more accurate the drilled hole is to the drilled axis, the smaller the pull back force.

As the pull back operation advances the partition of force in front of the pull head due to friction diminishes, just because there are fewer drilling rods in the drilled hole.

Methods for calculating the pull force.

In the past numerous attempts were made to develop a suitable calculation method to determine the pull force during the installation of the pipe.

Two of the calculation methods often applied are those according to the Dutch Norm NEN 3651 as well as the US-American AGA-Methods (AGA = American Gas Association, available converted into metric).

With both methods, the maximum expected pull force on the pull head of the pipeline can be calculated, whereby the maximum value occurs, just before the end of the pulling operation (i.e. when almost all of the pipeline is in the drilled hole).

Determining the size of the drilling rig

To determine the suitable size of drilling rig (rated pull force) there is as yet no common accepted calculation model. It should however be taken into consideration, that during the pulling operation, because of long interruptions or drilled hole collapses, a considerable higher pull force can occur than the one calculated with the above mentioned models. As reference value, depending on the geology to be drilled through, a safety factor of 2 to 5 is recommended.

This means that with a calculated pull force of maximum 300 kN, a drilling rig with a rated pull force capacity of 600 to 900 kN should be chosen.

Rig anchor

The pull forces of the drilling rigs must be securely taken up by a suitable anchorage.

It is recommended, that the dimensions of the rig anchorage is based on the maximum pull force expected.

Pipeline stresses

Concurrent with calculating the pull force requirements for the drill rig and the anchor system is the requirement to calculate the pipeline stresses during installation. The stresses to be calculated consist of longitudinal stress, bending stress and hoop stress.

Safety against buckling

Particularly with PE-pipes, evidence of safety against firstly buckling of the pipeline to be pulled and secondly against bending and drill fluid pressure is to be provided. The drill fluid pressure can, if necessary and in agreement with the client, be compensated for by applying an open pulling head which enables the inflow of the drill fluid into the pipe which is being pulled or alternatively by filling the pipe with water.

For installation the short-term Elastic Modulus can be used in the calculations.

➞ Operational conditions - Serviceability Limit State

Pipe stresses considerations

When determining the maximum pipe stresses, the proper combination of loadings and load factors shall be used for the governing pipe sections. When calculating the maximum pipe stresses for S.L.S., one of the essential loadings to be taken into account is the bending stress. The bending stress is a direct result of the imposed deflection on the pipe when it was pulled in a curved drilled hole. At the location where the applied tensile stress has been released the stresses arising from the internal pressure influence the maximum stress calculation.

Buckling strength

When determining the buckling strength for a pipeline in the S.L.S., the long term elastic modulus shall be applied. This is contrary to the short term elastic modulus during the installation phase.

Safety against buckling

The evidence of safety against buckling during the operating phase of the pipeline must - in contrary to the installation phase - take the long term Elastic modulus (PE-pipe) into account.

Also the soil load has to be observed.

Serviceable life

Occasionally evidence concerning the expected serviceable life under the respective operating conditions in the drilled hole is also required. This is especially relevant in heavily corrosive surroundings or at very high temperatures.

4.4 Construction schedule

A comprehensive construction schedule should feature at least the following work stages in connection with the execution of a horizontal directional drilling:

- Construction site installation
- Pilot drilling
- Reaming operation(s))
- Pullback operation
- Pipeline fabrication work
- Clearing of the construction site
- Reinstatement of site areas

The schedule in the form of bar charts has proven beneficial, whereby one day is the smallest unit in time. With the aid of such a schedule simple target/actual-comparisons can be drawn and the possible effects to the course of the work due to delays can be estimated.

Besides these „relative“ time details the following „absolute“ time details should also be included in the construction schedule:

- Earliest possible beginning of the works
- Latest permissible completion of the works

5 Safety and Environmental protection

The relevance of safety and environmental protection are to be comprehensively and thoroughly taken into account in the planning phase. During the execution of the project care is to be taken that constant adherence to the prescribed criteria is maintained. All valid national safety and accident-prevention regulations, and EC regulations and standards are to be adhered to. The particular dangers and risks listed below are supplemental to any other valid regulation and can in no way replace them.

5.1 Safety on the jobsite

Before beginning the works the entire personnel employed on the construction site are to be informed in a briefing about the danger of accidents and preventative measures together with all local rescue measures and organisations. The first-aid attendant, the responsible safety officer and if necessary the safety specialists must be presented to all employees. The following particular risks of the horizontal directional drilling are to be avoided by suitable preventative measures:

- **Working on inclined surfaces**
- **Working near rotating tools and machine components**
- **Increased danger of slipping due to drilling mud**
- **Dangerous strain on the respiratory tracts due to bentonite-dust**
- **Handling of suspended loads (drill pipes, reamer, etc.)**
- **Great torque when making up or breaking out drill string connections**
- **Communication between the control cabin, the drilling rig floor and the pipe site**

➤ **Working on inclined surfaces**

The working surfaces on the machines employed must be fabricated from particularly slip preventing and easy to clean materials. Sturdy railings must prevent personnel from falling.

➤ **Working near rotating tools and machine components**

The contact with rotating machine parts must be prevented as far as is possible by way of permanently installed protective guards. The work-clothes of operating personnel should fit tightly. Particular attention is to be paid to tight and closed arm-, body- and waist bands. During the rotation of the drilling rods, an adequate safety distance is to be maintained by all personnel.

➤ **Increased danger of slipping due to drilling mud**

When releasing the drill pipes, bentonite-suspension which flows out of the drill pipes should be conducted into collection basins and channels. Rinsing water for cleaning the working areas must be kept constantly available on the rig, equipment and at the mixing plants.

➤ **Dangerous strain on the respiratory tracts due to bentonite-dust**

Working under bentonite-dust is to be avoided as far as is technically possible and only permissible with dustmasks (particle-filtering half-masks) and close fitting protective goggles.

➤ **Handling of suspended loads (drill pipes, reamer, etc.)**

The handling of drill pipes and other loads with lifting devices is to be carried out with great care. Pipe clamps, lifting ropes and belts are to be regularly inspected for soundness. The feeding of drill pipes to the drill string should be carried out by stationary equipment, even at the drilling exit area. Standing under suspended loads is to be strictly avoided. An adequate safety distance from overhead power lines of all kinds must in all cases be observed and the strict procedures required by the national authorities should be adhered to at all times.

➤ **Great torque when making up or breaking out drill string connections**

Special care is to be given to observe correct and operationally safe methods for the making up and breaking out devices. In particular great care and attention should be observed when installing manual clamping collets and only experienced skilled personnel

should be used. Special care is also to be taken regarding correct and safe working conditions at the drilling exit area.

➞ **Communication between the control cabin, the drilling rig floor and the pipe site**

In order to eliminate particular dangers at the drilling rig site and the pipe site due to rotating tools, constant two way radio communication is to be ensured. When visual contact between control station and drilling exit area does not exist, it is recommended that, additionally to the normal use of hand radio devices, a „head-set“ (microphone and earphones) is permanently worn. In any case, a prior agreement with regard to communications is to be made between the driller and the person responsible at the drilling exit area.

5.2 Safety of machines

Rigs and equipment, which are employed on HDD-Projects should be in conformity with the European Machine Guidelines (EMG) and the National Machines Regulations derived from the EMG. A corresponding conformity declaration and the associated CE-symbol is to be supplied with the rig and other equipment by the respective machine manufacturers. Additional third-party monitoring of machines by the official national safety authority might be required and associated with the qualification ET for European Tested Equipment.

To avoid electrical hazards electrically driven machines and systems must be safe and adequately earthed before being started. The extensive hydraulic systems of the HDD-Rigs are to be carefully serviced and constantly inspected for leaks.

5.3 Safety of borehole tools

A safety certificate is to be provided (third-party monitoring) by a QM-qualified service company or a state approved technical inspection- and monitoring institution for drill rods, tools, devices, cross-overs, reamers and tool-joints, which run into a borehole. The certificates must prove, that the drill rods, tools, devices, cross-overs, barrel reamers, swivels and universal-joints used in the borehole are made from approved and suitable

materials and the maximum effective generalised strain from the pull force/tensile loading, torsion and internal pressure that can be delivered by the drilling rig employed, on the basis of the valid DIN, API and DS-1-Standards in no event exceeds the 0.8 yielding stress ($S = 1,25$).

For tools with rotating elements such as drilling motors, roller bits or swivels, it is to be ensured and documented on a record before every usage, that a careful inspection has been carried out and the unrestricted operational safety has been stated (self monitoring).

5.4 Environmental protection

Basically the horizontal directional drilling method puts less harm to the environment in comparison to the open cut construction method for pipe laying. When subsoil conditions are sensitive on the construction site, the access roads and working areas are to be made safe for heavy construction equipment and vehicles. Use of excavator mats is recommended.

When excavating ground for the necessary pits attention is to be paid to the type of topsoil and each additional soil layer. Separate storing is necessary and when back-filling, replacements the original sequence of soil layers has to be exercised.

Greatest care and attention is to be taken, that ground contamination due to spillage of oils, fuels or greases is avoided in all cases (use of oil, foils etc). Adequate oil-binding agents are always to be kept on the construction site for unforeseeable spillage occurrences.

Particular attention is to be given to safe storage and handling of drill fluid. Adequate (storage) pits have to be prepared in advance while at all times uncontrolled escape of drill fluid is to be prevented by all means.

The final disposal of residual fluid and cuttings is to be permitted by the local environmental authorities prior to start-up of the project.

A project is completed on acceptance of the restored occupied working areas to full satisfaction of the respective land owner(s).

6 Project execution

6.1 Personnel qualifications

The complexity of the horizontal directional drilling and the particular interest in the high standard of quality of its execution requires the engagement of carefully trained personnel both in the project management team as well as those in the operational team. The required training criteria as defined for example in Germany are as follows:

- ➔ **Driller**
- ➔ **Chief superintendent engineer**
- ➔ **Special supervisor according to the standard DVGW-GW 329 (Germany)**

Note: The standard DVGW-GW 329 (Germany) has been established with the input of DCA and will be published during 2001. DCA recommend the same initiative in other European countries where possible on the same base as the DVGW-GW 329. In the future certification of companies and employers shall be a requirement.

The definitions and tasks as specified in Germany are outlined as follows:

➔ **Driller**

The task of a driller is to operate the drill rig. A differentiation exists between drillers for a drill rig with a pull force of $\leq 400\text{kN}$ and drillers for a drill rig with a pull force of $> 400\text{ kN}$. Training takes place on separate courses according to DCA Training guidelines in training centres recognised by DCA. After successfully taking a written examination, participation is confirmed at the end of the training with a corresponding certificate of competency by the training centre.

➔ **Chief superintendent engineer**

The chief superintendent engineer is the manager of a work site who is permanently present on the construction site and responsible for the overall operations. Training takes place according to DCA-training criteria at a training centre approved by the association. A written examination and a certificate from the training centre confirm the successful completion of training.

➤ Specialist supervisor according to standard DVGW-GW 329 (Germany)

The training of a specialist supervisor and the subsequent examination of the knowledge by the DVGW is the prerequisite for a DVGW-certification of pipeline construction companies/specialist firms according to DVGW-worksheets GW 301 and 302 in the group GN 2 „controllable horizontal drilling techniques“. The following qualification criteria are authoritative for the specialist supervisor responsible according to DVGW-worksheet GW 329:

For drilling operations to be carried out with **drilling rig and pull force ≤ 400 kN**, at least 3 years professional experience and a successful training according to GW 329 are regarded as the qualification criteria for a completed training as master or technician.

For drilling operations to be carried out with **drilling rig and pull force > 400 kN**, at least 3 years practical experience as executive or head engineer in the drilling technique in combination with a successful training according to GW 329 are regarded as qualification criteria for a completed engineer-training.

6.2 Construction site installation and -clearing

6.2.1 Construction site installation

The setting up of a construction site for a HDD-drilling is carried out on the basis of a construction site installation plan and the existing utilisation- and rights of way authorisations. With larger works installations, as a rule the employment of a mobile crane with adequate lifting power is necessary. Suitable access and a safe work area for the lifting device are prerequisites for it. Necessary mud pits are to be excavated and made safe. External supply connections must, if necessary, be available on time. Safety-relevant contacts (Emergency doctor, rescue service, fire-brigade and police) are to be coordinated and posted on the bill board on site as a precaution.

6.2.2 Construction site clearing

On completion of a HDD-Project the building site is to be cleared immediately and the occupied terrain so restored, that it can be accepted and/or recultivated accordingly. The following works are to be organised:

- Cleaning the rig installation
- Cleaning and servicing the drilling rods (grease and protect threads)
- Removal of devices and installations
- Demobilisation of external supply lines
- Removal and disposal of drill fluid residues
- Removal and disposal of cuttings
- Reconstruction of temporarily removed installations (fences)
- Repair and reinstatement of supply roads

Record of acceptance with the owners or their legal representatives of occupied property and facilities is to be obtained.

6.3 Drilling work

6.3.1 Drilling technique

The execution of horizontal directional drillings is characterised by the following three work stages:

- ➔ **Pilot drilling operation**
- ➔ **Reaming operation(s)**
- ➔ **Pull back operation**

➔ Pilot drilling operation

During the pilot drilling, a drilling head is driven forward along a predefined drill profile by a drilling rig erected above ground. The push force and torque generated at the drilling rig is transmitted by the drilling rods to the drilling head.

At the beginning of the pilot drilling, the first part of the bottom hole assembly (BHA) consisting of drill bit, bent sub and non-magnetic drilling rods is pushed into the ground at the previously determined entry angle by the drill rig. The drill fluid which in general is made up of a Water-Bentonite-Suspension is pumped through the hollow rods to the bit nozzles and escapes at high pressure. Part of the loosened ground is displaced but most of it is transported to surface by the drill fluid flowing back through the annulus.

Each drilled rod is followed by another one from the drilling rig and the drilling process continues in cycles until the drilling head punches out at the target destination.

The respective position of the drilling head underground is determined with the aid of a sensor located right behind the drilling head, by using the Wire-Line-Method and utilising the existing earth's magnetic field and gravity, and is generally transmitted via cable to the control cabin. Due to this powerful measuring technology adopted from deep drilling technique, the method is practically suitable for all ranges of depths. In addition the so-called Walk-Over-Method is used on smaller drilling systems.

At locations with greatly disturbed magnetic fields, e.g. due to the geology or very intensively magnetic metallic constructions in the area of the drilled hole, gyro compasses are used more often as a system of measuring.

The control of the BHA is carried out via a reorientation of the drilling direction of the bit by small amounts, transferred by purposeful rotations of the drill rod, and the bent sub.

➔ Reaming operation(s)

After the controlled pilot drilling has exited at the target destination, the drill bit and the measuring probe are removed and replaced by a reamer. The purpose of the reamer is to open the hole up to the final diameter, a process, which may take several stages to complete. Several different types of tools are used to perform these operations depending on the type of ground being drilled. As a rule for soft grounds, barrel reamers are used whereas for medium to hard grounds fly cutters are used. For harder formations, such as rock, hole openers are engaged.

The reamer is pulled back rotating and jetting from the exit-side to the drilling rig. For each drill rod removed at the drill string, a new drill rod is added at the opposite work-side. In this way it is ensured, that a complete drill string is present in the drilled hole at all times. This procedure is repeated until the drilled hole has reached the intended final diameter. Each expanding cutting tool should always work to the same centreline as the previous drilled hole (stepped barrel reamer, stabilisers).

The conventional method of „back reaming“, when the reamer is pulled from the pipe site to the rig site, is occasionally replaced by „forward reaming“, when the reamer is

pushed into the ground from the drilling rig. In this instance, the pilot drilling serves as a guide for the reaming tool. Occasionally the drill string is also pulled from the pipe site by using a bulldozer which is connected to the drill string via a swivel. This method can provide high axial forces without risking buckling of the pipe which would be promoted by the push force between reamer and drilling rig.

➞ **Pull back operation**

During the final stage of carrying out a horizontal directional drilling the „welded“ pipeline is pulled into the completely expanded drilled hole. To pull the pipeline the reamer is rotated and pulled back under fluid circulation towards the drilling rig. Due to the connection with the pipeline via a swivel and universal joint the pull is thereby transmitted to the pipeline, but not the torque. The pipeline follows the reamer through the drilled hole up to the entry pit in front of the drilling rig without rotation.

In practice, to accelerate the pull back process, a slightly smaller diameter reamer is used than during the last expansion stage.

6.3.2 Drilling Rigs

Horizontal directional drilling rigs are generally sub-divided according to their maximum pull force. Thereby the following terms have become established:

- **Mini (drilling) Rigs**
- **Midi (drilling) Rigs**
- **Maxi (drilling) Rigs**
- **Mega (drilling) Rigs**

➤ **Mini (drilling) Rigs**

Mini (drilling) Rigs are used mainly in inner city areas and for laying PE-pipes and/or cables. These drilling rigs generate a maximum pull force of about 150 kN, maximum torque up to 10 kNm and their weight is about 10 t. Many of these Mini (drilling) Rigs are mounted on (rubber) track-driven chassis.

➤ **Midi (drilling) Rigs**

Midi (drilling) Rigs are often used at smaller water crossings or for special tasks such as in environmental technology. These rigs generate a maximum pull force of about 150 to 400 kN, torque of about 10 to 30 kNm and their weight is about 10 to 25 t. These Rigs are also normally mounted on track-driven chassis and are accordingly suitable for rough terrain.

➤ **Maxi (drilling) Rigs**

Maxi (drilling) Rigs are used for large drill lengths and borehole diameters. They are mainly applied on gas pipeline routes, where water-, railway line- or large roads have to be crossed. The maximum pull force of these Rigs amounts between 400 and 2.500 kN, the torque between 30 and 100 kNm and the weight between 25 and 60 t.

➤ **Mega (drilling) Rigs**

Mega (drilling) Rigs are designed for extreme drilling lengths and borehole diameters. They are intended to be used on long-distance pipeline routes in Eastern Europe and Asia. The maximum pull force of these drilling rigs is over 2500 kN, the torque over 100 kNm and the weight over 60 t.

Drilling Rigs (Type)	Max. Pull force in kN	Max.Torque in kNm	Weight in t
Mini	≤150	< 10	< 10
Midi	> 150 bis ≤ 400	10 – 30	10 – 25
Maxi	> 400 bis ≤ 2.500	30 – 100	25 – 60
Mega	> 2.500	> 100	> 60

Fig. 6.1: Classification for horizontal drilling installations.

Horizontal directional drilling rigs consist of a steel frame with a movable drilling carriage mounted on it. This drilling carriage transmits the necessary power (and torque) to the drill string. The inclination of the steel frame can be adjusted by supports at one end of the unit. This is necessary in order to be able to set the required entry angle for the drilling process.

The main features that describe the design of a drilling device are

- **Substructure**
- **Power Transmission**
- **Power Range Limit**

➤ **Substructure**

The substructures of the horizontal drill rigs vary between the following designs:

Frames

The simplest method of construction a horizontal drilling device consists of the drill carriage mounted on a steel frame and then simply providing supports at one end of the frame with which the necessary entry angle can be set.

The advantages of this construction design are the simple and robust method of

construction as well as the relatively light weight. Disadvantage is, that mobile cranes with considerable lifting capacities are needed respectively for the unloading/assembly procedure and after the drilling operation for the dismantling/ loading procedure.

Trailer

A widely used method of construction is the assembly of the steel frame on a trailer. With this design a relatively large degree of mobility on the road and on fortified tracks is achieved at relatively little cost.

Disadvantage is the limited off-road capability. In addition, most drilling rigs of this type have the pulling device at the front, in consequence of at the moment the drilling is completed the pulling machine must drive into the area of the entry pit, which then has to be filled. Otherwise the drilling trailer must be moved by an auxiliary device for example an excavator, in such a way, that the tractor can be hooked to the trailer on relatively clean ground.

Track-driven chassis

An undercarriage construction in the form of a track-driven chassis has in the meantime gained ground as the version often chosen for small and medium sized drill rigs. Moreover, maxi rigs have been fitted with suitable track-driven chassis.

The advantage of this method of construction is the great off-road capability. By using the drive engine as the power supply, quick readiness for utilization at the location is possible just as with a wheel-driven chassis. In addition to the great weight, the disadvantage here is also the relative high costs.

Wheel-driven chassis

The drill rig can also be mounted on a self-propelled wheel-driven chassis whereby the drive engine normally provides the power supply for the drilling device.

With this method of construction greater off-road capability can be realised with a suitable chassis in comparison to a normal trailer design. The disadvantage of this construction is often the very heavy weight and high cost. Overall, this type of construction has not been able to establish itself.

➔ **Power Transmission**

With regard to the mechanical power transmission to the drill carriage, there are the following arrangements:

Chains

Chain-drive represents a safe and simple power transmission. A chain belt which is on the drilling carriage is driven by hydraulic cylinders, similar to the caterpillar drives.

This form of power transmission has proven successful particularly with small and medium sized drill rig.

Rack and Pinion

The combination of pinion-wheels and racks probably represents the most robust type of power transmission. Pinion wheels driven by hydraulic motors are located on the drilling carriage. The mesh with racks are integrated in the steel frame. Very great forces can be realised with this type of construction.

Disadvantages are the relatively great weight and the generally low driving speed of the drilling carriage.

Hydraulic cylinders

Hydraulic cylinders transmitting power to the drilling carriage are the latest technical development in this field. Already very widely used for small and medium sized installations, they are also increasingly used on large and very large drill rigs.

Hydraulic cylinders can be very smoothly driven and have a favourable power-speed-ratio. The disadvantage is their relatively large sensitivity, and particularly the often unprotected guided piston rods. Repairs are rarely possible in the field, only very specialised workshops can repair large hydraulic cylinders.

➤ **Power Range Limit**

The power range limit of the drill rig depends, in addition to the mechanical parameters of the drilling installation also on the hydraulic capacities of the pumps and the mixing installations. The site geology plays quite a decisive part in determining the possible drilling length and diameter. Furthermore, the pipe-specific parameters such as weight, surface roughness etc. must also be taken into account. Also, attention is to be paid to the course of the borehole axis amongst other things the curvature radius etc. must be observed.

6.3.3 Drill String „Standards“

The following general details are significant in connection with drilling strings:

- **Dimensions**
- **Grades and Properties**
- **Tool Joints**
- **Loads**

➤ **Dimensions**

The number and the application of drill pipes in the horizontal directional drilling technique depends mainly on the pull force - and torque capacity of the drilling unit.

inch	2.3/8	2.7/8	3.1/2	4	4.1/2	5	5.1/2	6	6.5/8
mm	60,3	73,0	88,9	101,6	114,3	127,0	139,7	152,4	168,3

Fig. 6.2 Drill pipe (API)

Smaller horizontal drilling rigs normally work with special pipes of up to 6 m length and diameters between 40 and 60 mm.

On larger drilling units the drilling rods used in deep-drilling technology according to API-Specifications have proven successful (API = American Petroleum Institute). API-drill pipes are available in diameters 2.3/8" (= 60,3 mm) to 6.5/8" (168,3 mm). These drill pipes can be supplied in three length groups (Ranges). (see Fig. 6.3)

Ranges	Length w/o Tool Joints [m]	Length incl. Tool Joints [m]
Range 1	5,49 – 6,71	-
Range 2	8,23 – 9,14	8,60 – 9,50
Range 3	11,58 – 13,72	-

Fig. 6.3 Ranges

➔ Grades and Properties

The drill pipes should be manufactured exclusively seamless rolled according to API-regulations. For the steel grade, one differentiates between various grades, whereby the current range lies between „Grade E“ (yield point = 515 N/mm²) and „Grade S“ (yield point = 927 N/mm²).

Drilling rods are subject to enormous wear due to friction during their usage, especially in abrasive hard rock drilling. The actual wall thickness of the drill pipe is measured, in accordance to the API-guidelines in four stages of quality (Classes) differentiated between (Class I =new; Premium; Class II, Class III), all depending on the degree of wear.

➔ Tool joints

The tool joints on drilling rods from the deep-drilling technology are as a rule manufactured as tapered threads. With this a secure coupling and fast releasing of the tool joints is ensured when connecting actuated by adherence. Pipe box and threaded pin are always to be kept clean, to be carefully prepared with an approved thread grease and must be capped (protected) against damage and dirt immediately before and after use.

There are detailed technical classifications for tool joints, like standards, dimensions and inspection rules in the API-guidelines.

Special drill pipes, mainly produced for smaller drilling units, should be fabricated, obeying as far as possible, the fundamental drill string standards and technical criteria of the API-guidelines .

➔ Load types

The horizontal directional drill string should be engineered to withstand the maximum expected loads, including the safety factor. Loading types to be considered are:

Axial Tension Loads

Axial tension loads occur, when the drill string must be pulled out of the borehole, whereby as a peculiarity of the horizontal directional drilling technique, from experience, the greatest tensile loads on the drilling rods occur when the „protective or product-pipes must also be drawn into the borehole.

Axial Compressive Loads

Axial compressive loads occur when the entire drill string is put under compression by the carriage of the rig pushing the drill pipe into the ground. i.e. particularly the drill bit, being forced against the borehole base.

Torsion Loads

Torsion loads occur, when the drill string is rotated by the rotary motors at the carriage of the rig and this rotary motion is transmitted to the drilling tool. When drilling with downhole motors, the torque produced is absorbed by the drill string.

Bending Loads

Bending loads on the drill string are the result of the curved design profile of the drilling axis. As the string rotates, such as during the expansion stage, each drilling rod and in particular each tool joint is permanently subjected to an alternating bending load. This creates a considerable load on the materials, which is further increased when using a tighter borehole radii.

6.3.4 Drilling Tools

With regard to the drilling tools, a general differentiation is possible with the aid of the work stages:

- ➔ **Drilling tools for the pilot drilling**
- ➔ **Drilling tools for the hole opening/reaming**

➔ **Drilling tools for the pilot drilling**

For soft and loose ground, generally a „Jet Bit“ is used. The bit loosens mainly hydraulically the ground in front of the tool. Jet Bits can be differentiated with regard to their dimensions, respectively in length between approx. 300 mm to 1000 mm and in diameter between approx. 40 mm and 200 mm.

A further differentiating feature lies in the number and the diameter of the jetting nozzles used. As a rule, no more than five nozzles are used with a opening diameter between 1 mm and 10 mm.

To achieve control of the drilling head, there is either a steering surface on the head of the Jet Bit or the entire pipe of the Jet Bit is angled by a small amount. Apart from this, it is possible to generate steering impulse by an eccentric arrangement of the nozzles and / or a non-axial installation of the nozzles in the jet bit.

With medium-hard and medium density ground or hard rock, jet roller bits are used. These bits destroy the rock predominantly mechanically.

Jet roller bits differ with regard to the bit arms, the jet seats, the bit rollers and the bit bearings. For these tools there is a comprehensive coding according to IADC-Code (IADC = International Association of Drilling Contractors).

To generate the required torque down hole base motors are used for the jet roller bits. Control is achieved via a short, angled drill pipe (Bent Sub) between drill string and drilling motor.

With very hard and dense rocks, hard-metal tools are used.

➔ Drilling tools for the hole opening/reaming

For reaming various types of tools are used depending on the type of ground. With soft ground these tools are normally so-called Barrel Reamers. These reamers are designed with a cylindrical, barrel-shaped steel body, which has jet nozzles at the front and back.

Fly-Cutters are designed and constructed more open and shorter than barrel reamers. Fly-Cutters mainly consist of a cutting ring connected to the central drill pipe via three or more struts. Jet nozzles can be found both in the cutting ring as well as in the struts. Straight-shaft bits are also mounted on the ring and the struts as mechanical protection incl. realisation of the cutting. These types of tools are suitable for medium-hard ground.

With very hard formations (rock) Hole Openers are used. Hole Openers are similar to oil-field drilling tools. They generally consist of hard-metal rollers that are arranged around a central, very stable drill pipe. Jet nozzles fitted to the Hole Openers clean the rollers and transport the cuttings away from the borehole front.

In order to achieve optimal centralisation during the reaming stages, barrel reamers should be stepped in diameter and the front section should equal the diameter of the previous reaming operation. Fly-Cutters and Hole-Openers should be fitted with stabilisers or cylindrical centring reamers for centralizing the drill string, to prevent meandering as far as is possible during the reaming stage.

6.3.5 Drilling Fluid

The composition of the drill fluid is determined by the results of the geological investigation executed in line with the framework of the project planning before construction work begins. The following fluid properties are to be taken into account in particular:

- **Density**
- **Viscosity**
- **pH-Value**
- **Circulating Volume**
- **Solids content**

➤ **Density**

Due to the specific density of the drilling fluid, the required hydrostatic (over)pressure (slightly overpressured ground water) in a drilling can be exerted to the ground. The density of the fluid increases constantly due to the cuttings. It is therefore necessary to measure continually with the aerometer or the mud balance the mud going down-hole and the returning mud. A clean Water/Bentonite basis fluid has a density of between 1,02 and 1,06 g/cm³. With that, the requirements of a drilling fluid are fulfilled for most applications.

➤ **Viscosity**

Viscosity (Unit: mPa * s) is understood to be the resistance of the fluid with respect to the flow. Two values of viscosity exist, apparent viscosity and plastic viscosity.

A viscosity matched to the drilled ground ensures the hydraulic properties of the drill fluid, particularly the transport of the drilled solid material and the pumpability. The parameters of the fluid can be modified by using viscosity-forming additives.

As a measuring unit for this, the time for 1 Liter. of drilling fluid passing through the „Marsh-Funnel“ (Marsh Viscosity) is used in most cases. If necessary, a rotating „Fann viscometer“ provides precise values for yield point or the plastic viscosity (Bingham model). Detailed information about hydraulics and load-carrying capacity of the drilling fluid can be derived from these values.

The following Marsh funnel viscosities for drilling fluids can be assumed as reference values (for comparison: Water at room temperature about 28 sec):

– clayey ground	30 – 40 sec
– sandy ground, cohesive	35 – 40 sec
– sandy ground, non-cohesive	45 – 60 sec
– Coarse sand	60 – 80 sec
– Coarse gravel	> 80 sec
– Mixed ground:	according to coarsest grain fraction

Project specific, (e.g. solid rock drillings or difficult loose rock drillings) it can also become necessary to determine the flow curve (shearing strain / shear gradient), the gel strength or dynamic fluid pressures of the drilling fluid. For this viscometer measurements are necessary.

➔ pH-Value

The pH-Value controls the physical-chemical structure of bentonites and determines their electrochemical charge which conclude the effectiveness of the drilling fluid and in addition also the effectiveness of additives.

The pH-Value is an important reference value for assessing the chemical reaction of the drilling fluid.

The pH-Value of bentonite fluids should be between about 8,0 and 10,0.

➔ Circulating Volume

The circulating volume (in ltrs/min) has to be monitored constantly and documented, particularly for the early detection of fluid losses or -thinning. The danger of borehole collapse or from ground upheavals can be detected early from such differences, and necessary action implemented.

The required flow capacity results from the geological condition of the drillings and the carrying capacity of the bore fluid.

The total fluid quantity is estimated from the borehole volume and a factor of fluid loss into the ground. This factor is normally - depending on ground information - between 1,05 and 2,20.

$$V_B = \frac{\pi \cdot d_A^2}{4} \cdot L_B \cdot f_K$$

V_B	=	<i>Borehole volume</i>	$[m^3]$
d_A	=	<i>Final diameter of the borehole</i>	$[m]$
L_B	=	<i>Length of the drilling</i>	$[m]$
f_K	=	<i>Factor for fluid losses</i>	$[-]$

➤ Solids content

All insoluble components of the drilling fluid are called solids. Depending on grain size, a differentiation can be made between colloidal, silt or sand. The determination is carried out by sieving according to API and with the sand measuring glass. The solid content (in Vol %) serves to assess the carrying capacity, the pumpability and the abrasion capacity of the mud and together with the transported volume, the proof of cleanliness of the borehole and the effectiveness of the separation devices (sieves, cyclones, centrifuges) used in recycling of the mud.

6.3.6 Locating System

There are three types of locating systems in the horizontal directional drilling technique, which can be basically differentiated as follows:

- **Walk-Over-System**
- **Wire-Line-System**
- **Other Systems**

➤ Walk-Over-System

This method of measuring is mainly used with smaller drilling installations, whose maximum drilling depth lies about 10 m under ground surface (see Fig. 6.4). When using the Walk-Over-System, an electromagnetic signal is emitted from a battery-driven

transmitter which is installed immediately behind the drilling head. This signal is received by an antenna on the surface above and registered on the sender device.

As a rule this antenna analogously tracks the drilling head's progress underground. By way of the signal strength, the operator can locate the transmitter with regard to the lateral position and depth. In addition he receives information about the current working direction of the drilling tool (Tool-Face).

The advantage of this system is, no cable connections, which are labour-intensive and prone to failure. Apart from this, the operation of the system of measuring is relatively simple and quick to learn. Because of this, the Walk-Over-procedure is a relatively low cost surveying system.

The disadvantage of this system is its measuring accuracy which reduces greatly with the drilling depth as well as its proneness to interference from magnetic influences from the substratum or due to other magnetic fields. In addition to this, the energy reserves which, are limited by the battery capacity - particularly in longer drillings - can be regarded as a disadvantage for larger crossings.

To be able to successfully carry out a pilot drilling with a Walk-Over measuring system, the terrain profile above the planned bore axis must be measured exactly before drilling begins. The absolute values determined from the measurement probe (distance of the transmitter from terrain surface or from receiver) can then be integrated with the recorded terrain profile. In this way the actual-course of the drilling can be documented.

The quality of the data transmission is, amongst other things, dependent on the depth of the probe under the terrain surface, the conductivity of the ground layers present, the inclination of the transmitter, the stability of the receiver, the external influences of electromagnetic fields in the bore line as well as the actual energy capacity of the batteries used.

As a reference value for the accuracy of a measurement with the aid of the Walk-Over system, a decline of about 10% can be assumed up to a depth of about 5 m. With unfavourable framework conditions (e.g. inclination of the measurement probe in rising or falling segments of the borehole) this value can fall back +/- 50 cm.

➔ Wire-Line-System

This measurement system is mainly applied to larger drilling rigs and accordingly, to long and deep drillings (cf. Fig 6.4). It has been developed from the measurement system used in deep drilling and can be used for practically all depth ranges.

With the Wire-Line system, there is also a measurement probe with magnetometers and inclinometers as close behind the drilling head as possible. Its measurement values are transmitted via a cable connection, that runs through the inside of the drilling rods and above ground to the control cabin. There, the information is processed in a computer and stored.

The reference system of the measurement probe orientates itself during the execution of the pilot drilling on the earth's gravity field (Inclination) and on the earth's magnetic field (Azimuth). In addition, the surveyor also receives information about the actual working direction of the drilling bit (Tool-Face).

With the aid of inclination and azimuth, a progression - starting from the point of entry - can be constructed, that represents the actual position of the pilot drilling. The details about the Tool-Face are needed, in order to be able to steer the drilling head in accordance with the actual development of the bore line.

The advantage of the Wire-Line system is, theoretically no depth limit of the bore line and the energy supply to the measurement probe also takes place via the cable connection plus the information is almost continually available. In addition the transmission of the measurement values via cable itself is not prone to disturbances.

A disadvantage of this procedure is, the very sensitive measurement probe reacts particularly critically to magnetic fields of interference in the bore line (railways, sheets piles, high voltage lines etc.).

To compensate for the interfering magnetic fields, a cable loop can be laid out on the surface above the bore axis to generate an artificial magnetic field. This blanks the ambient magnetic field because of its greater field strength. The measurement probe in the ground now detects this new magnetic field and transmits its actual position with reference to the cornerstone points of the previously accurately surveyed cable loop, to the control cabin.

With this system, the surveyor has all the „absolute values“, that is positional details of the measurement probe with reference to the terrain surface.

To successfully carry out a pilot drilling with the Wire-Line measuring system, the measurement probe must be calibrated exactly before drilling begins. The coordinates and heights of the entry and exit points must be known precisely, since both these points are the reference points of the polygon of the bore line.

As reference values for the measuring accuracy of the device, when using the artificial magnetic field under optimal conditions, a value of about +/- 5% related to the depth of the measurement probe under the terrain surface can be assumed.

	Max. Drilling depth	Accessability of the ground above the drilling axis necessary	Interference due to magnetic fields
Walk-Over	ca. 10 m	yes	yes
Wire-Line	without a.m.f. *1)	> 100 m	no
	with a.m.f. *2)	ca. 30 m	yes
Gyro compass	> 100 m	yes	slight
		no	no

Fig. 6.4: Summary of the various locating procedures with details of the fields of use
(*1) without a.m.f = without artificial magnetic field / *2) with a.m.f. = with artificial magnetic field)

➡ Other Systems

With drillings that must be carried out in areas with strong magnetic fields, the use of a gyro compass is increasingly coming into consideration (see Fig. 6.4). These measuring instruments were also developed in the deep drilling technology for use in bore holes.

Gyro compasses work independently from the earth’s magnetic field and thereby can - independent of the environmental conditions - very accurately determine the direction of a bore axis. This advantage compensates for the disadvantage of the relatively great sensitivity with regard to mechanical loads (blows etc.) as well as the relatively high costs of usage. Apart from this, practice has shown that gyro compasses are indeed precision instruments, the success of their use however is decisively dependent on the qualifications of the operating personnel.

Another interesting measuring device for horizontal drillings is the parallel bore measuring systems. These are used when several pilot drillings with relatively modest lateral distance must be carried out more or less parallel in one location.

In these cases, a pilot drilling is first measured conventionally with the Wire-Line-System. After the first drilling is completed, these drilling rods remain in the borehole and serve as a protective pipe for a transmitter, for example drawn through this steel pipe with a steel cable.

Further the second pilot drilling starts, parallel to the first one, whereby the transmitter in the first pilot drilling is guided at about the same direction as the measurement probe in the second pilot drilling. The impulses emitted from the transmitter are registered in the receiver probe, transmitted above ground (via cable) and evaluated. The driller then receives the results of the three-dimensional position of the new pilot drilling related to the already produced and accurately measured first pilot drilling.

The accuracy of the measurement lies with a lateral distance of 10 m at about $\pm 0,3$ m. If the distance between the two bores is less, then the measurement accuracy increases proportionally.

6.4 Pipeline construction work

6.4.1 Pipe materials

For installations underneath obstacles with the horizontal directional drilling technique the following pipe materials are suitable:

- **Steel**
- **Ductile cast iron**
- **Polyethylene/Polypropylene**

➔ Steel

Steel pipes are used predominantly to transport gases and liquids with high operating pressure. The jointing of individual pipes is carried out by manual or automatic welding technology. The coating requirement of the pipes is provided according to the specific technical requirements as follows.

- Steel pipes, uncoated: As protective pipe for sensitive transport systems (combined pipe bundle, cable)
- Steel pipes, internally and/or externally Epoxy coated, externally PE-insulated: Transport systems for gasses and liquid hydrocarbons. (Also: externally Epoxy coated)
- Steel pipes, internally Epoxy coated, externally PE-insulated, additionally with glass-fibre-reinforced plastic or fibre-reinforced cement coating: Transport systems for gasses or liquid hydrocarbons in geologically hard ground.
- Steel pipes, internally cement coated, externally PE-insulated: Transport systems for drinking water
- Steel pipes, internally cement coated, externally PE-insulated, also externally with glass fibre reinforced plastic or fibre-reinforced cement coating: Transport systems for drinking water in geologically hard ground

➔ Ductile cast iron

For HDD-installation pipes made from ductile cast iron are fitted with suitable connector ends and -sleeves, further jointed longitudinally with a special sealing system up to diameter of 1000. With these pipes, in particular the permissible axial forces (including a safety factor) and the maximal permitted angling at the joints according to Fig. 6.5 are to be adhered to. With the permissible pull force, hereby a safety factor of 1.5 is taken into account. The permissible line lengths are for pipes made from ductile cast iron in accordance to DIN EN 545 and wall-thickness class K10 with cement-mortar coating according to DIN 30674, part 2. The friction resistance has not been taken into account.

- Application: Ductile cast-iron pipe systems are used to transport drinking water and waste water, particularly for aggressive waste-water.

Nominal diameter DN	Conpling system	Construction system test pressure (PEA) in bar	Permissible pull force in kN	Permissible angling in degrees	Permissible bending radius in m
100	TIS-K	45	49	3	115
150	TIS-K	45	102	3	115
200	TIS-K	45	174	3	115
250	TIS-K	45	265	3	115
300	TIS-K	45	376	3	115
400	TIS-K	30	434	3	115
500	TKF	37	822	2,5	140
600	TKF	37	1172	2	172
700	TKF	30	1283	1,5	230
800	TKF	30	1670	1,5	230
900	TKF	30	2104	1,5	230
1000	TKF	30	2588	1,5	230

Fig. 6.5: Steel pipes made from ductile cast iron with details of permissible longitudinal loads including a safety factor and the maximal permitted angling in the joints

➤ Polyethylene/Polypropylene

Polyethylene pipes (PE-pipes) and particularly pipes made from Polyethylene high density (PE-HD) are extruded endlessly and supplied accordingly, their length is only limited by transport capabilities. When being pulled into the HDD-drillings, buckling due to static pressure of the bore fluid must be prevented by suitable measures (open pulling heads or filled pipes).

- Application: Transport systems for drinking water and natural gasses with low operating pressure. PE- and PE-HD pipes can be fitted with an additional outer layer as damage protection.

6.4.2 Pipe protection

Steel pipes are normally protected against corrosion and/or mechanical damage by a special coating.

- ➔ **Coating**
- ➔ **Protection coating**
- ➔ **Lining**

➔ **Coating**

The coating of steel pipes is normally executed in the factory, while the joints are done on the construction site (field joints).

Factory coating are mainly manufactured from polyolefines and fitted in a three-layer-system after completion of the pipes at steelplant and consist of

- Epoxy-resin base coat
- Adhesive
- Polyethylene or Polypropylene

With the factory-fitted coating, the pipe ends remain free from coating for a suitable length, leaving space for the connection of the steel pipes by welding on the construction site.

For subsequent coating of the welded seams on the construction site, the following systems exist:

- Polyolefine-Systems (Polyethylene or Polypropylene)
- Duomere-Systems (Epoxy-resin or Polyurethane)

For all systems mentioned, it is of great significance, that these are suitable for the particular stresses in the HDD-process. Besides the ensured insulation quality, which should equal the factory coating at all cost, a secure adhesion against peeling on the steel pipe and a bonded overlapping of the factory coating must be guaranteed.

Coating of steel pipes serves particularly to protect against corrosion.

➤ **Protection coating**

For the use of steel pipes coated with Polyolefine-Systems in the HDD-process, it is often necessary, to protect the PE- or PP-coating additionally against mechanical damage from stone inclusions etc. in the borehole walling.

With this in mind, the pipes can be fitted with an additional fibre-cement mortar casing. In critical ground conditions, an even more resistant casing made from a Duromere System (e.g. Glass-fibre-Epoxy resin) can be fitted.

➤ **Lining**

Linings for the inner walls of pipes are generally manufactured in the factory and serve particularly to protect against inner corrosion. The welded seam area can also be subsequently lined with these coatings on the construction site.

For the use of all coating systems, in all cases the respective valid national and European technical regulations must be maintained.

6.4.3 Pipeline Stringing and Overbend

In connection with the pipeline construction work on horizontal directional drilling projects, the following elements are to be particularly emphasised:

- **Pipeline stringing on rollers**
- **Pipeline stringing without rollers**
- **Overbend**

➤ **Pipeline stringing on rollers**

The pipe string prepared for the pull back operation is normally put on rollers. The rollers reduce the frictional resistance to a minimum and thereby reduce the pull force required by the drilling rig during pull back of the pipe string.

Rollers are normally a steel frames, on which hard-rubber rollers with ball bearings are mounted. The roller width can be adjusted at some models, so the same roller can be used to accept various pipelines sizes.

When setting up the rollertrack, attention is to be paid, that the distance between the rollers does not become too large, thereby causing the pipeline to buckle or to slide to the floor between the rollers. Apart from this, rollers should be inspected before the pull back process begins, as to whether all rollers have been well lubricated and a blocking of the individual rollers during the pull back process can be safely excluded. With heavy pipe strings, it must be demonstrated, that the permitted pressure load of the outer pipe insulation is not exceeded.

➞ Pipeline stringing without rollers

To guide pipe strings made from ductile cast iron, conventional rollers are not suitable. For pipe strings made from ductile cast iron, steel sheets should be installed, supporting the string at each sleeve connection. Thereby, it is to be ensured through suitable measures, that the outer corrosion protection is not damaged during the pull back process.

➞ Overbend

At the exit point of a horizontal drilling, the drill string exits at a particular angle out of the ground. To prevent the pipeline from buckling when being pulled in at this point, it is necessary to transfer the pipeline in a suitable curve (so-called overbend or „catback“) from its horizontal position on the conveyor to the exit angle. Thereby, no non-permissible loads (Stresses) may occur in the pipe string.

To reduce the maximal height of the overbend, in practice the curvature of the overbend is begun in the exit pit. The first roller behind the exit point is elevated (e.g. on earth mounds or other supports). The height of the individual supports as well as their distance to each other must be carefully calculated in order to avoid non-permissible loads.

Equally, for safety reasons, attention is to be paid to ensure that all roller supports can safely accept the expected longitudinal- and lateral forces, without slipping or tilting over.

6.4.4 Ballasting

In the event that large and light pipe strings are to be pulled into a borehole, attention is to be paid to the considerable force introduced to the string in the borehole and as a result pressed with relatively great force against the borehole face. In combination with the respective friction coefficient, this force in cases generates considerable frictional forces between the pipe string and the borehole wall. These frictional forces must be overcome by the drilling rig.

To reduce the negative aspects (higher pull forces) of a high friction in the borehole, the pipelines can be ballasted (i.e. fitted with weights). Particularly suitable for this action is filling the pipelines with water - if necessary in combination with a linear displacer, incorporated at regular intervals, or a separately incorporated ballasting pipe. Water is very easy to remove after the pull back process is complete, and on the other hand, the inner of the pipe is not mechanically damaged.

In connection with the above it is recommended, to fill the ballast water only in that part of the pipe already in the borehole. Normally a small filling line is used, inserted on the inside of the pipeline. The reason for this procedure is to overcome the problem that all rollers would be burdened with the weight of water in addition to the weight of the pipes. This would make a significant shortening of the distances between the rollers necessary and thereby a considerably greater number required.

An ideal ballasting is achieved, when the pipe string in the borehole only generates small positive or negative bouyancy and these components of the pull backforce can be reduced.

7 Approval

To provide evidence of the quality assurance, inspection acceptances are to be submitted both during and after the completion of the execution of the project of horizontal directional drillings as well as after the completion of the work of individual work stages. The respective required approvals should be agreed in writing between the client and the contractor before construction work begins. The approvals should be recorded and signed by both contractual parties.

The entire listing set out below would not necessarily apply to each project. A project-specific suitable selection is to be made each time.

For many of the points listed, there are corresponding regulations in the national regulatory works, on which these approvals should be orientated.

- **Approvals before the pull back of the pipe string**
- **Approvals during the pull back process**
- **Approvals after the pull back of the pipe string**

➤ **Approvals before the pull back of the pipe string**

- Inspection of welds
- Leak test of product pipes
- Inspection of factory- and field coating
- Inspection of additional protective joint coatings
- Visual inspection of the pipe string
- Strength of design of the pullhead and the rig anchor
- Safety of the pull backtools
- Stability and load capacity of the rollers under the pipe string

➤ **Approvals during the pull back process**

- Pull force within limits of the pipe
- Prevention of damage to the coating

➔ **Approvals after the pull back of the pipe string**

- Removal of ballast when applied
- Resistance measurement of the coating
- Calibration of the pipe diameter with a caliper pig
- Leak test of product pipelines
- Depth measurement with a barometric system
- Overall position survey with a gyro compass
- Annulus fillings
- Controlled waste disposal
- Removal of residues
- Restoration of land, pipe site, rig site etc.

The respective agreed approvals are to be enclosed with the documentation and handed over to the client. A copy is to be retained by the contractor.

8 Documentation

8.1 Records

For all work stages of a HDD-project, an up-to-date record is to be maintained. This is also valid for the possible necessary ballasting of the product line as well as for an eventual filling of abandoned drill holes (filling report).

Essential elements of the records of working procedures are:

- **Daily report**
- **Drilling records**
- **Minutes of meetings**

➤ **Daily Report**

The following details must be evident in the construction log:

- Location
- Date
- Weather
- Project
- Safety instructions
- Work executed
- Sub-contractor work
- Personnel engaged
- Equipment used
- Material consumption
- Special events

➤ **Drilling records**

The values are as a rule to be recorded for each work stage. The following data must be evident from the drilling records:

- Station
- Time

- Azimuth, Inclination and Toolface of the drilling head
- Pull/thrust on drill pipe (kN)
- Torque (kNm)
- Pump rate (l/min)
- Pump pressure (bar)
- Special events

With larger drillings the following fluid data is to be recorded at regular intervals also:

- Density
- Viscosity
- pH-Value
- Circulating volume
- Solids content

➔ **Minutes of meetings**

Minutes of meetings serve to provide up to date information between the client and the contractor. A record is to be prepared regarding the content of the meeting and submitted to the participants.

8.2 As-built documents

All as-built documents and documentation are to be submitted to the client, in accordance with previous agreements, after completion of the works. The as-built documents should contain the following components:

- ➔ **Drawings**
- ➔ **Records**
- ➔ **Photo documentation (optional)**

➔ **Drawings**

- Overview plan (Scale: 1: 5.000)
- Longitudinal section, plan, cross-section (Scale: 1:100 - 500) as well as construction planning- and construction as-built documents (can be combined).

➔ Records

- Terrain restoration
- Approval

➔ Photo documentation (optional)

- Construction areas before beginning of the works
- Most important operations
- Construction areas after completion of the works

9 Appendix

Fig. 1 Schematic Drill Profile

Fig. 2 Schematic Showing Site Equipment (Site layout)

Fig. 3 Pilot Drilling and Pullback Assembly (Schematic)

Fig. 4 Schematic Drilling Operations

Fig. 5 Schematic Overbend

Fig. 1: Schematic of Drill Profile

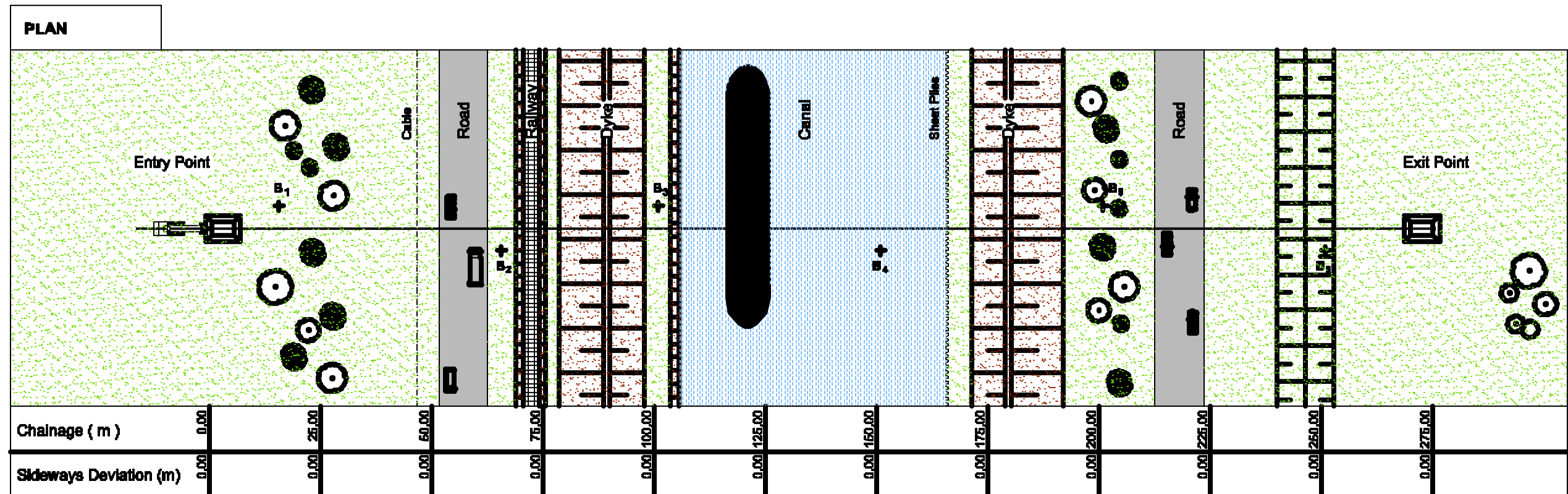
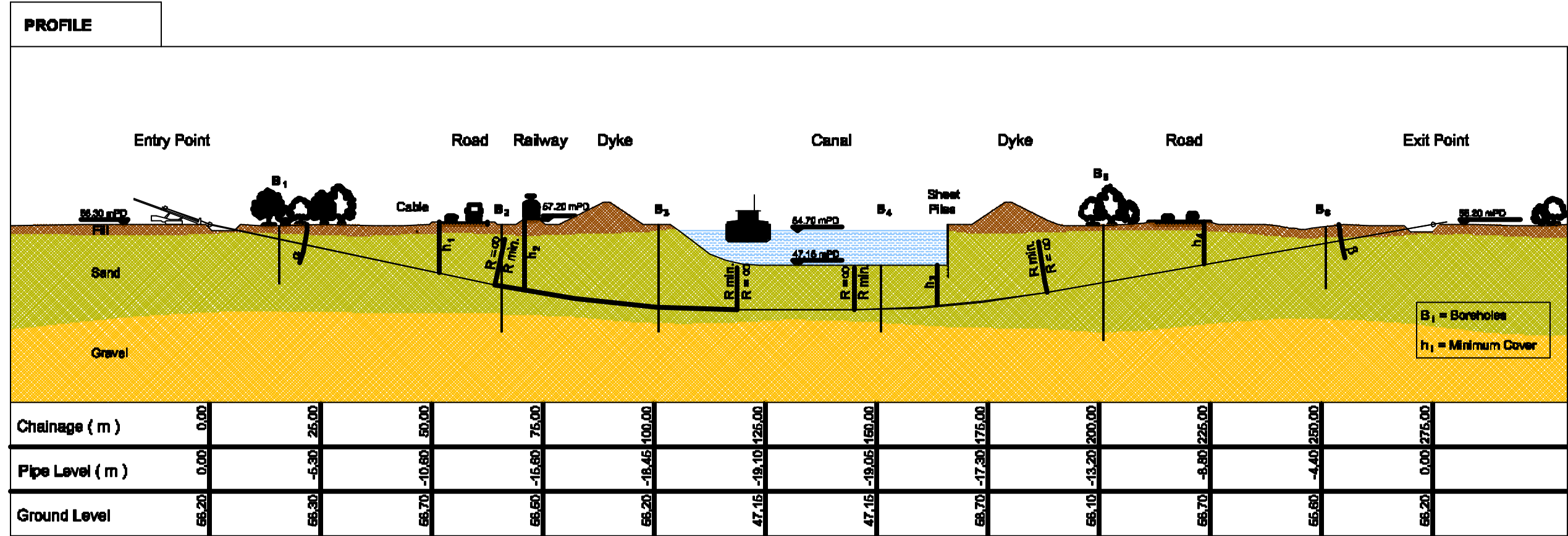


Fig. 2: Schematic of Showing Site Equipment

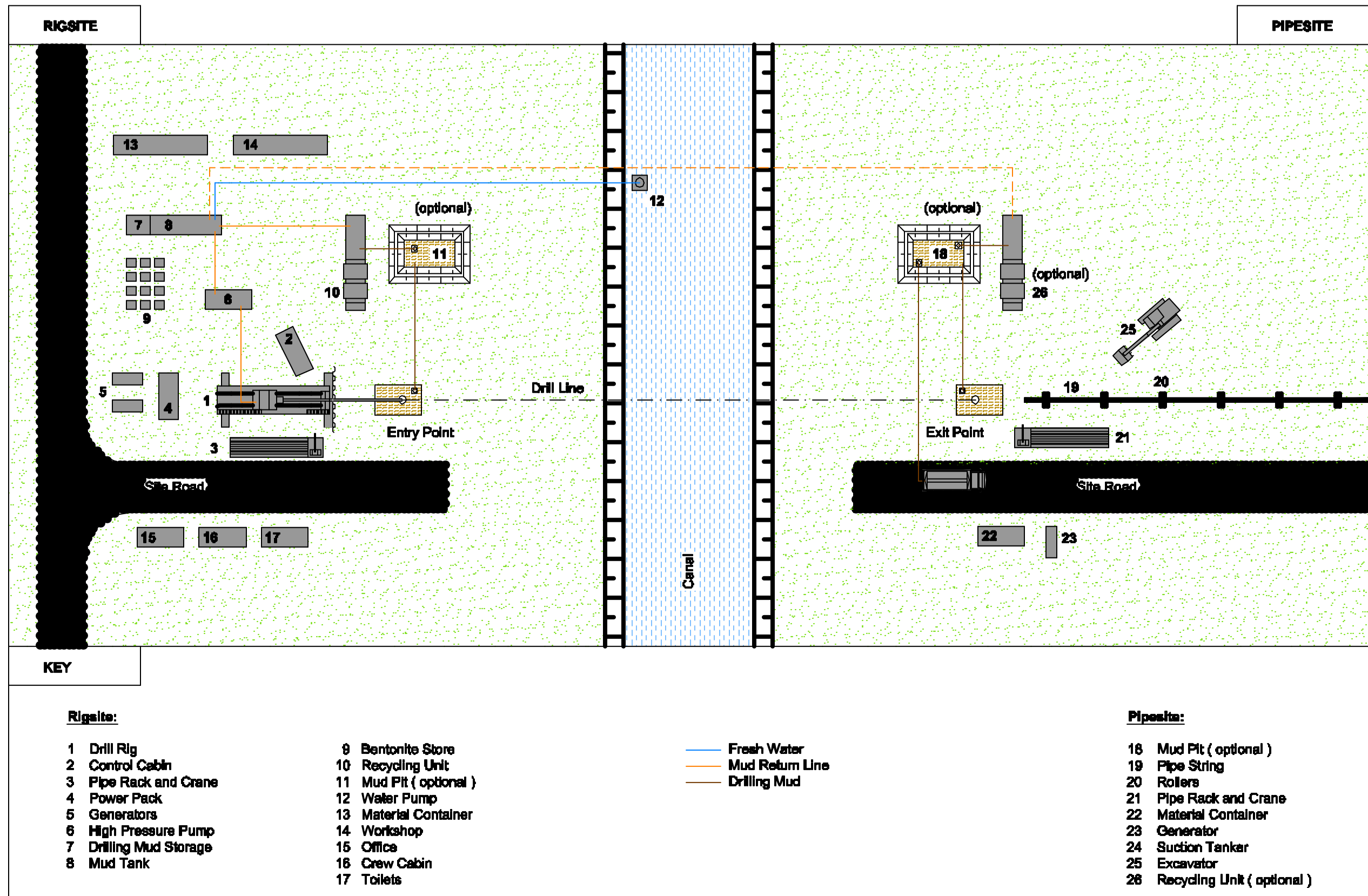


Fig. 3: Pilot Drilling and Pullback Assembly

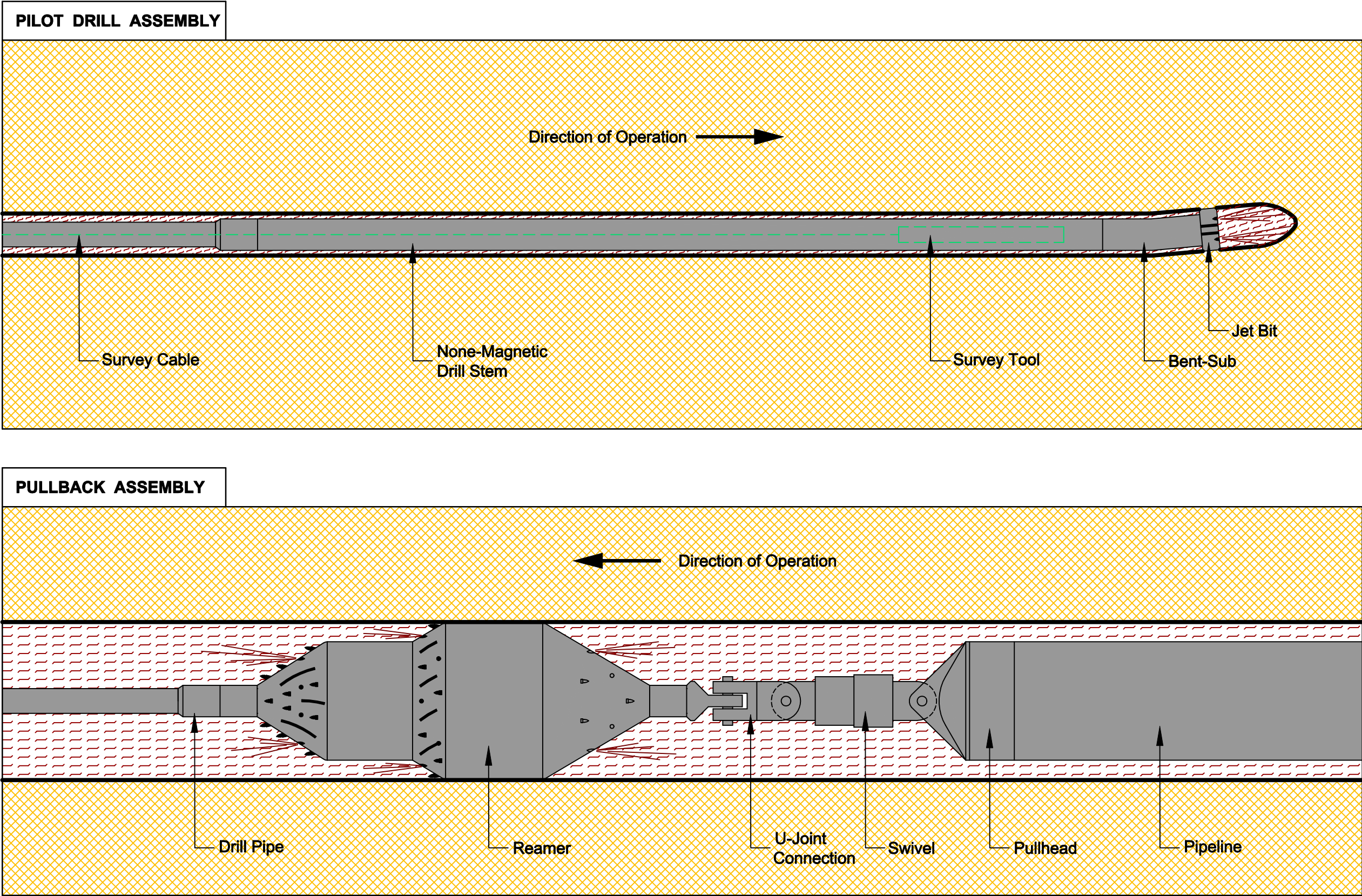
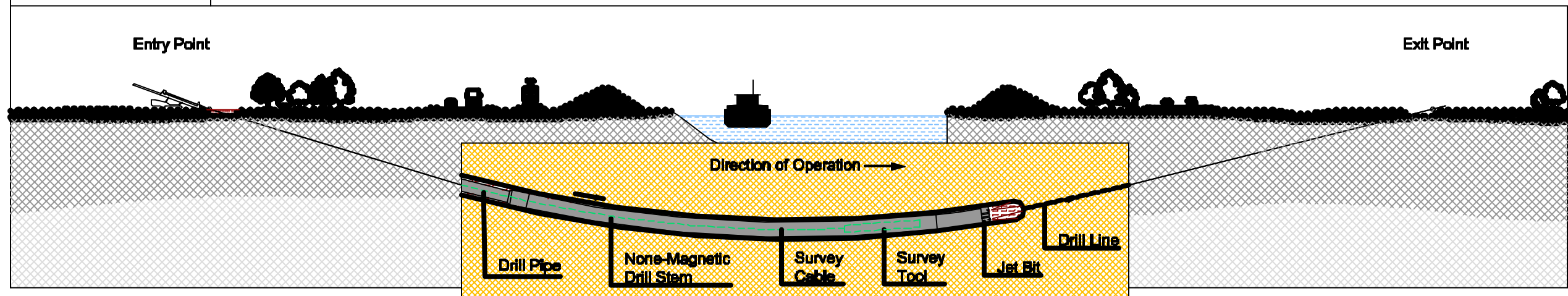
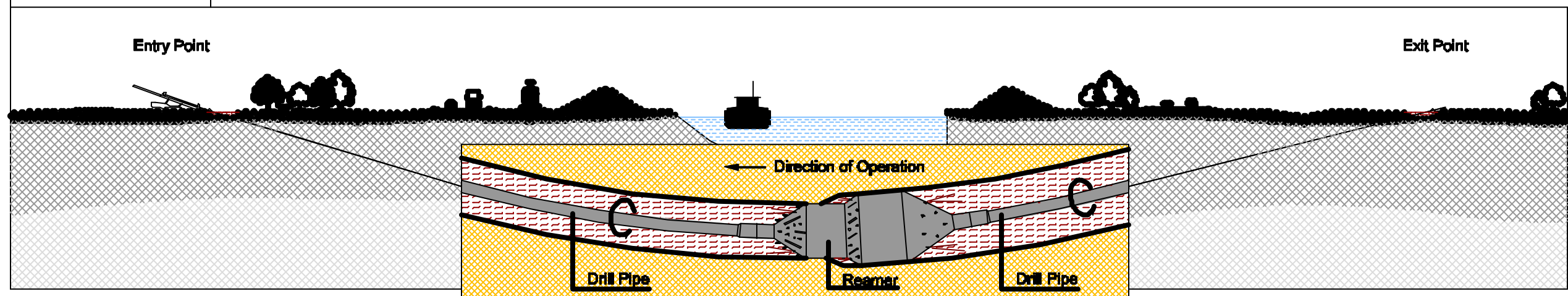


Fig. 4: Schematic of Drilling Operations

PILOT DRILLING



REAMING



PULLBACK

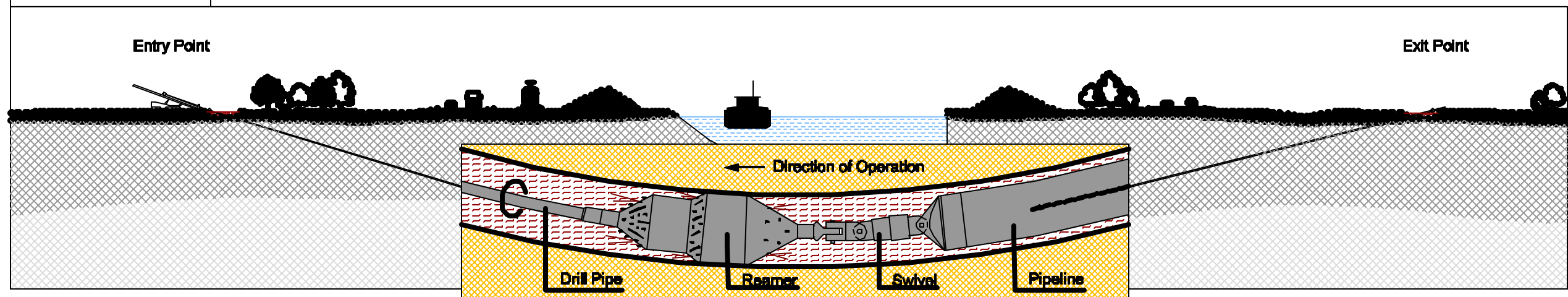


Fig. 5: Schematic of Overbend

