Drilling Contractors Association
Verband Güteschutz Horizontalbohrungen
Association des Entrepreneurs de Forage Dirigé

large scale drilling

small scale drilling

Pipe casing and coating in HDD

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Foreword

The Drilling Contractors Association (DCA) was founded in December 1994 by leading companies in the horizontal drilling industry as a technical association in Europe. Horizontal Directional Drilling (HDD) has been developed since the late 1970s from deep drilling technology and has now established itself worldwide as a technical and economic alternative for crossing obstacles in the field of pipeline installation.

Pipeline infrastructures are the lifeblood of modern society, and trenchless construction methods, particularly horizontal directional drilling, are now indispensable in the construction of this infrastructure.
The primary goal of the association is to maintain, promote and further develop the technical standard of horizontal drilling at the European level. In addition, the general framework conditions for the use of this method should be improved primarily by unifying quality assurance standards, standardizing approval procedures, and promoting education, research, and development.

The task group established by the board in 2019 initially aimed to analyse the current situation regarding the materials used for HDD technology, testing procedures, and related regulations. Furthermore, measures/recommendations should be developed to ensure the quality of the coatings on behalf of the client and help HDD-companies to identify and report errors and risks before taking over the product pipe (often provided by the client or third parties).

The present Technical Information No. 6 „Pipe casing and coating in HDD“ of the DCA gathers the working results of the task group and provides information on all parameters, processes, and interactions that have an influence on coating quality. In addition, the Technical Information helps in selecting the most suitable coating system for specific drilling and soil conditions.

All information and recommendations in this document apply to standard HDD drilling but can be similarly applied to related trenchless applications such as pipe jacking, direct pipe, installation of product pipes in micro-tunnels and conduits with HDD-Rigs, etc. as long as individual conditions are considered.

The present Technical Information No. 6 complements the DVGW-worksheet GW 340 and the norms DIN 30340-1 and DIN 30340-2.

The board of the association would like to thank all those involved in the task group who participated in the creation of Technical Information No. 6 „Pipe casing and coating in HDD“ of the DCA.

Aachen, March 2024

Drilling Contractors Association (DCA-Europe)

Content

1 Introduction

Pipelines are increasingly being installed using Horizontal Directional Drilling (HDD) and related methods. These pipelines can be part of different systems, such as gas pipelines, water lines, sewer channels, or cable ducts, and can be made of either plastic or steel. Steel pipes are typically provided with a protective corrosion coating. Any damage to this coating during installation can negatively impact the condition of the pipeline system and potentially result in the client rejecting the installed pipeline. The significance of the error is not only determined by the size of the damaged area, but also by the soil conditions, such as below the water table, in sandy or clay formations, or in peat, and whether the pipeline can be effectively protected through cathodic corrosion protection (CCP) with reasonable effort.

According to the definition in DIN 30340, the DCA Technical Information No. 6 also distinguishes between a coating of the steel pipeline, which usually serves only corrosion protection, and an additional casing, which usually serves the mechanical protection of the pipeline against external influences, both during open-trench installation and during trenchless installation, e.g., with HDD technology. A reinforced coating can provide both corrosion and additional mechanical protection. When both the coating and the casing are mentioned, this is referred to as the protection system. For better readability of the text, the term „re-coating“ is used for both the re-coating and the re-casing of the welded seam areas. No linguistic differentiation is made.

The coating of steel pipes is mostly applied during production at the pipe factories. The casing can either be applied at the pipe factories or at special facilities. The pipes are coated individually and all relevant parameters, such as (pipe) temperature, humidity, material, curing times, etc., can be controlled by the skilled personnel. The welding seams between each pipe must be coated on-site at the pipeline location, under less favorable conditions. This report focuses on the most used coating systems in Europe, discussing various systems for both factory-applied and field joint coatings. These systems do not have to be made of the same material, and if a combination of materials is used, they need to be compatible with each other. In a multi-layer system, the outer layer serves as a mechanical protection and the inner layer as a corrosion protection.

There are standards and/or specifications for all of these systems, however, they are not always comparable as different materials have distinct properties. Not all of these standards are specific to HDD and many generally refer to the material and its use. Some coatings have specifications that are provided only by the manufacturers and can vary slightly. Additionally, it is important to note that there may be country-specific differences in standards for coating or acceptance criteria.

A damaged coating can have various causes, some of which may be within the responsibility of the HDD contractor, others within the responsibility of the pipeline contractor, and some may stem from the faulty selection of the protective system in relation to the subsoil being drilled.

The cost of the protective system in relation to the total cost of the pipeline, including installation, is typically less than 1%. The application of a high quality protective system therefore does not impose an excessive burden on the project budget. However, installing a protective system tailored to the project conditions can save money and avoid unnecessary discussions between the client and contractor in the aftermath. Nonetheless, more expensive is not always better; it depends on the right choice of protective system.

The work of the task group revealed that the complexity of coating products in HDD projects is so great that there is a high demand for additional information and support. This importance has also been recognized by other organizations, such as the French gas operator GRTgaz, which has developed an application called OPTIDRILL to determine the best suitable coating material according to the project conditions. However, it should be noted that this tool is only for internal use at GRTgaz and does not cover all the coating systems available on the market.

2 Motivation

While laying steel pipelines using HDD, it is common practice to use the successful testing of the coating after pullback as a contractual acceptance criterion for the drilling work carried out by an HDD contractor. This serves as evidence that the HDD contractor has fulfilled his contractual obligations to the client and is entitled to full payment for the drilling work.

Some causes of coating damage may fall within the responsibility of the HDD contractor, such as the use of inappropriate drilling equipment and tools, failure to comply with drilling parameters, disregard of guidelines, etc. However, not every deficiency in the coating is necessarily the result of poor execution by the HDD contractor.

Even if the drilling works are executed according to all applicable standards, rules, guidelines, best practices, etc. and an ideal borehole geometry has been created, coating damages or imperfections can occur due to:

- the selection of an inappropriate factory coating material,
- the selection of an inappropriate casing material,
- the selection of an inappropriate field joint re-coating material,
- poor application quality, particularly with field joint re-coatings,
- the residual geotechnical risks that are the responsibility of the client (e.g., collapse of the borehole in unknown/uncontrollable formations, sharp-edged rocks on the borehole wall, passing through heterogeneous weathering zones, etc.).

In most cases, these causes are outside the control of the HDD contractor. However, in the event of detecting a coating damage after pullback, it is difficult to definitively assign responsibility to one of the parties involved in the project. As a result, it is more effective to optimize the quality of each relevant step in the project to minimize the possibility of coating defects after the pipeline is pulled back.

The HDD contractor is generally responsible for ensuring that a properly drilled borehole is created, which has the required minimum diameter, no dog-legs (sections with too tight radii), and has conducted an adequate number of cleaning runs. The pipeline contractor must ensure that the field joint coating is applied correctly. Studies carried out by the creators of Technical Information No. 6 of the DCA and practical experiences have shown that this is often not the case. Thus, the quality of the field joint re-coating application on the construction site is a major cause of damage occurrence. Furthermore, preparing the pipeline for pull back (i.e. positioning of rollers, construction of the overbend) is usually the responsibility of the pipeline contractor, without compromising the quality of the field joint coating.

Since the steel pipes are typically ordered well in advance, the client often decides on the protective system to be used, even before the HDD project planning is completed. This can result in the chosen coatings on the pipes not being optimally suitable for the actual local soil conditions encountered on site.

During the work of the task group, it became clear that the quality of the casing and coating material and its application on the pipe (in the factory and particularly during the field joint coating application on site) are the most crucial factors for a successful installation without damage to the coating. To ensure adequate quality of the field joint coating (FJC) of the on-site welds, personnel with necessary training and experience must be deployed. Therefore, a special emphasis must be placed on this aspect during the procurement of services. In addition, the use of an experienced coating inspector, working on behalf of the client, is highly recommended.

3 Importance of corrosion protection

A compatible active and passive corrosion protection system is essential for preserving the integrity of a newly installed steel pipeline and ensuring its proper functioning. This is of critical financial importance if the pipeline is to reach its intended service life.

Passive corrosion protection includes all measures that maintain an effective barrier against corrosive elements such as humidity and oxygen. This is achieved by applying an appropriate coating or protective covering over the base material (steel), considering the construction method and soil conditions. A corrosion protection coating is a barrier layer that protects the steel surface of the pipe from corrosive elements (electrolytes) in the surrounding soil.

In addition to passive corrosion protection provided by the coating, a steel pipeline typically also has active corrosion protection through cathodic protection (CP). To ensure effective cathodic protection, certain conditions must be met and monitored through measurements, including:

- The number and area of defects
- Electrical and electrochemical influences
- Soil conditions
- The layout of the CP system

If there are defects in the coating, the CP system acts as an additional layer of protection. However, the protective effect of the CP system in this case is limited.

Cathodic protection has been a trusted method for preventing external corrosion on buried pipelines for many decades.

This method not only minimizes the costs of repair work, but also helps to maintain the value of the pipeline in the long run. In addition, an active corrosion protection system enables monitoring of the coating‘s integrity.

The importance of cathodic protection and its effectiveness are particularly relevant for pipeline sections installed using horizontal directional drilling (HDD). In most cases, repair work at such depths is either impossible or impractical due to high costs.

In many countries, the requirement for an active corrosion protection is primarily, if not exclusively, determined by national legislation and technical standards for pipeline installation. Further information can be found in the relevant national regulations.

As pipelines are increasingly being laid near power lines and high-voltage overhead cables, which can cause interference, even minor coating defects can pose a significant risk of alternating current (AC) corrosion. Even if they fall under the maximum permissible contact voltage of 60 V (as per AfK recommendation No. 3), the risk of AC corrosion remains high on existing coating defects. Therefore, based on the recommendations in CEN/TS15280 standard, a pipeline with a flawless coating is the simplest and safest way to avoid AC corrosion.

4 Importance of application quality

The selection of the pipe material, the corrosion protection system, and if necessary, the additional mechanical protection, is crucial for a successful HDD installation. Certain borehole conditions can make the pipe susceptible to damage, so the highest quality standards must be adhered to. The quality of the coating system, combined with the geological conditions surrounding the borehole, is the primary factor in determining whether coating defects can be prevented during the installation process.

In addition to the quality and proper selection of materials, the quality of processing and application also plays a crucial role, particularly for field-applied coatings. It is essential that the personnel applying the coating are trained and certified. Before application, the specification of the material must be verified to ensure its suitability for the requirements and conditions of the crossing.

Special attention must be given to prevailing weather conditions as most coating systems are sensitive to humidity and temperature. The chosen coating system can only be applied correctly by experienced and qualified personnel using the right tools and equipment and following the manufacturer‘s procedures.

5 Quality assurance and quality control

The acceptance of a HDD project is significantly based on the demonstration of the effectiveness of the corrosion protection system after the completion of the construction project. The corrosion protection can still be ensured with a damaged coating, provided that there is sufficient protection potential.

Despite all precautions, defects in the coating cannot be ruled out. Therefore, it is necessary to ensure that the coating of the pipeline being pulled back is intact and that any field-applied coatings are correctly applied before pullback.

It is also possible to detect coating defects during pullback. As with the final evaluation of the construction project, measurement methods in cathodic corrosion protection play a special role here.

This section describes the essential aspects of on-site testing methods for demonstrating the processing quality before, during, and after the pipeline pull-in. Destructive and non-destructive testing methods need to be differentiated.

In addition to these quality assessments, a monitoring of the execution quality is necessary as the available quality assessments may not reveal all product and processing faults. A specially trained and qualified supervisor, referred to as a „Coating Inspector,“ should be employed for this purpose (see also DVGW Worksheet GW30).

As previously described, many defects in the coating of newly laid pipelines are due to poor execution and lack of quality control of the coating (factory and on-site coating). The integrity of the pipeline can usually be increased through quality control during construction. If defects remain undiscovered, repair work, if at all possible, at a later stage, may incur significant effort, both economically and technically. Through effective on-site testing, many of these undetected defects

can be detected and remedied in a timely manner before the trench is backfilled or the pipeline is pulled into a borehole. This can avoid costs for subsequent repairs. For this reason, the apparent additional costs of hiring a sufficiently qualified Coating Inspector on site are easily justified.

Qualified ‘coating inspector’ must have (from DVGW worksheet GW 30):

- Ability to assess the execution of pipeline coating works,
- Experience with passive corrosion protection and fundamental knowledge of cathodic corrosion protection in the field of metal pipelines or installations buried in soil or water, or laid above ground,
- Special knowledge in the areas of coatings, corrosion, corrosion protection, detection methods, measurement devices, application methods, and safety measures, and the ability to work on problem-solving,
- Knowledge of technical standards relevant to coating,
- Qualifications to implement and supervise all coating works and explain proper execution,
- Ability to prepare technical instructions for all persons involved and assess all data collected on these tasks,
- Personal capacity for factual, unbiased, independent, and objective analysis and documentation, as well as the ability to communicate effectively and convincingly in both written and spoken language.

The coating inspector has the following tasks and responsibilities; their scope and nature will be defined by contract for a specific project. The coating inspector should preferably be commissioned by the client of the measure (DVGW GW 30):

- Planning, execution, supervision, and documentation of quality control (on the construction site, including measuring contacts)
- Review qualification of pipe coaters prior to works commence,
- Quality assurance in the planning and execution of passive corrosion protection,
- Assessment of application and remedial procedures,
- Quality control at the manufacturing plant,
- Setting up/evaluating and coordinating the test and supervision plan and quality control of passive corrosion protection,
- Assessment of the quality, suitability and conformity of the coating materials used in accordance with existing guidelines (DIN, EN, ISO, DVGW, company standards, construction contract, project specifications, etc.);
- Assessment, condition monitoring and documentation (visible transport damages, etc.) of coated pipes, fittings and components both at the factory and on site,
- Evaluation and documentation of existing coating, casing, and re-coating systems and their application,
- Assessment of existing quality documentation (factory certificates, test reports, etc.),
- Participation in meetings relevant to their role, e.g., site consultation meetings, condition monitoring, acceptances and meetings related to change of order or defects;
- Carrying out tests on site (surface condition, surrounding conditions like climate, application defects, etc.) after a test plan or randomly;
- Support in reporting and correction of defects as well as its documentation
- Documentation and assessment of passive corrosion protection as well as provide assistance in assessing the corrosion protection through an Expert in accordance with DVGW G100 (A) Specialty Area IX, and in initial proofing of function of corrosion protection after DVGW GW10 (A) and DIN EN ISO15589-1.

The need for a detailed explanation of coating quality criteria is unnecessary, as it typically does not determine whether a system is suitable for use in HDD projects. Quality checks only evaluate the correct application of a specific coating type, and not the entire coating system‘s fitness for use, which may consist of various combinations of different coating materials and layers. These quality checks also do not consider the potential stresses and strains that may occur during pullback operations in a borehole.

6 Quality control

6.1 Testing methods prior to pipe insertion

6.1.1 Coating thickness measurement

Unless otherwise specified, the minimum thickness of the field joint coating, measured in any area without welds (including circumferential, longitudinal, or spiral welds), must be no less than 90% of the nominal thickness. The nominal thickness is the calculated sum of all layers before application.

These tests are performed using a magnetic, electromagnetic, or ultrasonic device. To avoid creating a locally increased mechanical load on the field joint coating, the thickness of the field-applied weld coating should not exceed the thickness of the original factory coating.

For further information, refer to the international technical standard DIN EN ISO 2808.

6.1.2 Adhesion testing

Adhesion testing is a destructive method that requires qualified personnel to perform. It involves cutting a specific pattern into the anti-corrosion coating to reach the metal substrate using a suitable tool. A field joint coating is then pulled off perpendicularly from the metal surface using an adhesion tester, either manually or automatically, while measuring the required force. The detailed testing procedure and the minimum values that must be achieved can be found in the respective standards for the coating material.

For further information, please refer to standards such as DIN EN 12068 or DIN EN ISO 21809-3.

6.1.3 Shore-Test

The Shore D Hardness scale is primarily used to measure the hardness of elastomers, rubbers, and polymers. It is directly related to the depth of penetration and is therefore an indicator of the material‘s hardness. A spring-loaded steel rod is used to make an indentation in the sample, and the depth of the indentation indicates the Shore D Hardness.

The testing procedure is described in DIN EN ISO 868, and the minimum Shore D values required can be found in the respective coating material standards. These standards provide the specific testing procedure and minimum requirements for each material.

6.1.4 Electrolytic discontinuity testing

Comparable tests of pipeline coating quality using high-voltage (see Chap. 6.1.5) and electrolytic methods have demonstrated that in practice, the high-voltage method cannot detect all types of coating discontinuities (such as non-linear pores/cracks). The electrolytic method, according to DVGW Worksheet GW 10 (June 2018), simulates the conditions of a pipe that is buried in the ground and fully in contact with the soil. The test involves first placing a plastic cuff around the area to be examined (usually a recoated weld seam) and sealing it off with a sleeve to prevent any fluid leakage. The section is then immersed in electrically conductive, low-surface tension water, and a suitable metal anode is inserted in the space between the sleeve and the coating section. The electrical potential applied to the pipe section through the auxiliary anode (e.g., a 24V battery) helps determine the required coating resistance (see Figure 1).

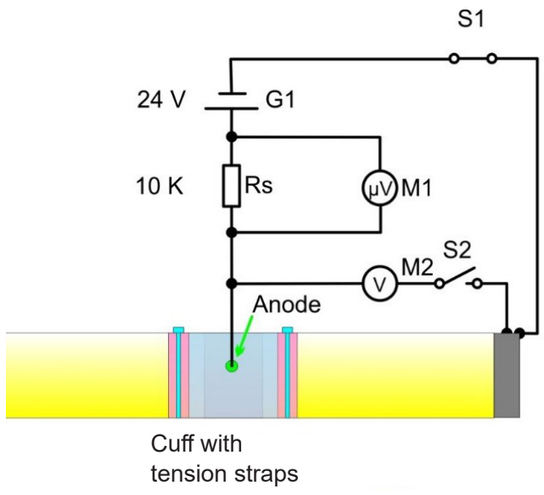

Figure 1: Diagram of the electrolytic process

In both cases, the coating resistance can be calculated as follows:

$$ru = R \cdot A = (UM2 / IM1) \cdot A \; [\,\Omega m^2]$$

6.1.5 Testing of complete pipe string – high voltage Test

Pipeline coating integrity is typically evaluated using high voltage testing methods, known as the „Holiday Test,“ which is a non-destructive method used to detect discontinuities such as pinholes and voids in protective coatings. During the test, an electric current is sent through the coating to check if it completes the circuit, which helps to identify gaps in the coating film that are not easily visible.

The voltage level applied during the test depends on the coating system and thickness, and the dielectric strength of dry air, which is approximately 3kV/mm, must be considered. If a discontinuity is detected between the grounded steel pipe and the test device electrode, an arc becomes visible and an alarm sounds.

To detect a discontinuity, the void must be nearly perpendicular to the surface of the coating and have a short distance between the two conductors. However, bonding imperfections in cased coatings cannot be detected.

When it comes to pipelines being pulled through a HDD borehole, the Holiday Testing provides relatively limited quality assurance. This is because it can only verify the integrity of corrosion protection in dry conditions and without mechanical loads. As a result, any imperfections under another additional mechanical coating, such as GRP, cannot be detected (see 7.2.3).

When pulling back a pipeline, various mechanical loads are applied to the coating and the pipeline can become embedded in drilling fluid and groundwater. Any imperfections in the mechanical protection coating that occurred prior to pullback could result in damage to the corrosion protection coating, due to the weight applied. Therefore, a mandatory visual inspection of the mechanical protection layer before pullback is necessary. Additionally, fluid in the borehole could seep into any previously undetected, untight bonding imperfections, act as an electrolyte, and enable an electric current to flow between the steel pipe and the coating, which leads to corrosion. This can occur even if there is no further damage caused by mechanical loads.

In summary, a Holiday Test with no detected imperfections before pulling a pipeline into a borehole does not guarantee that the coating, which includes both corrosion and mechanical protection layers, is of the required quality. Imperfections that go undetected before pullback will be discovered through an impressed current test / DCVG after the pullback.

Therefore, it is recommended to perform the Holiday Test multiple times before pulling the pipe string into the borehole, especially when it is positioned on pipe rollers. Additionally, the Holiday Test should be done during the pull-in process, directly in front of the borehole entry, in order to detect and repair any last-minute damage, such as that caused by the rollers.

6.2 Quality check while pulling

To ensure the quality of the pipe string during pullback, measures can be taken to prevent damage. However, there is still a risk of defects occurring that cannot be remedied after installation, such as those caused by AC corrosion. In such cases, the „Pull & Check“ method can be considered. This method involves continuously electrolytically testing the pipe coating while the pipe is being pulled through the borehole. To do this, a special pulling head with electrical isolation from the pipe itself is required.

<u>Application Note:</u>

When pulling a pipe into position, the detection of coating damage allows for prompt action to be taken. In order to obtain an acceptable and defect-free coating, the pipe could be pulled back out of the hole and the coating repaired. Consideration should be given to reconditioning the borehole before pulling the pipe back into the hole. It is important to note that removing a large section of pipe that has already been positioned can cause additional damage to undamaged sections, which will require repairs over a greater length of pipe.

All equipment necessary for a successful pullback operation, including reliable rig or winch anchorage, must be available on-site and in working order.

6.3 Quality testing after pullback

6.3.1 General information

After the pipe has been pulled into position and the bottom hole assembly has been detached from the pull head, the ends of the pipe are cleaned and dried. In order to demonstrate that the coating is free from defects, a current requirement test is performed to determine the coating resistance (see section 6.3.2). This test is carried out by measuring the resistance of the coating. The coating is considered free from defects if the measured coating resistance is ru ≥ 108 Ωm² which is the minimum coating resistance specified by current standards for factory coating (e.g., DIN 30670) or field joint coatings (e.g., DIN EN 12068). Fig. 2 provides a graphical representation of the measured resistance value. The specified coating resistance of ru ≥ 108 Ωm² can be reduced and regulated by contract on a project-specific basis.

If the minimum required coating resistance is not achieved, a polarization resistance measurement, including a comparison with defects, should be performed (see 6.3.3). In Germany, this is typically based on the polarization testing procedure recommended by the AfK (no. 1 and no. 10), as well as standardized methods for testing the polarizability and applicability of cathodic corrosion protection to trenchless pipe installations in current technical literature. If inadmissible coating damages are detected, repair of the pipe coating must be carried out after locating the position of the coating defect. However, repair works, which can only be done with reasonable effort, are often limited to the sections of the pulled-in pipe string with moderate soil coverage.

In case of an inadmissible measurement result, it is recommended to first confirm the accuracy of the measurement or the execution of the measurement before taking further steps, which are usually associated with considerable effort. Experience in practice has shown that measurements can also be flawed.

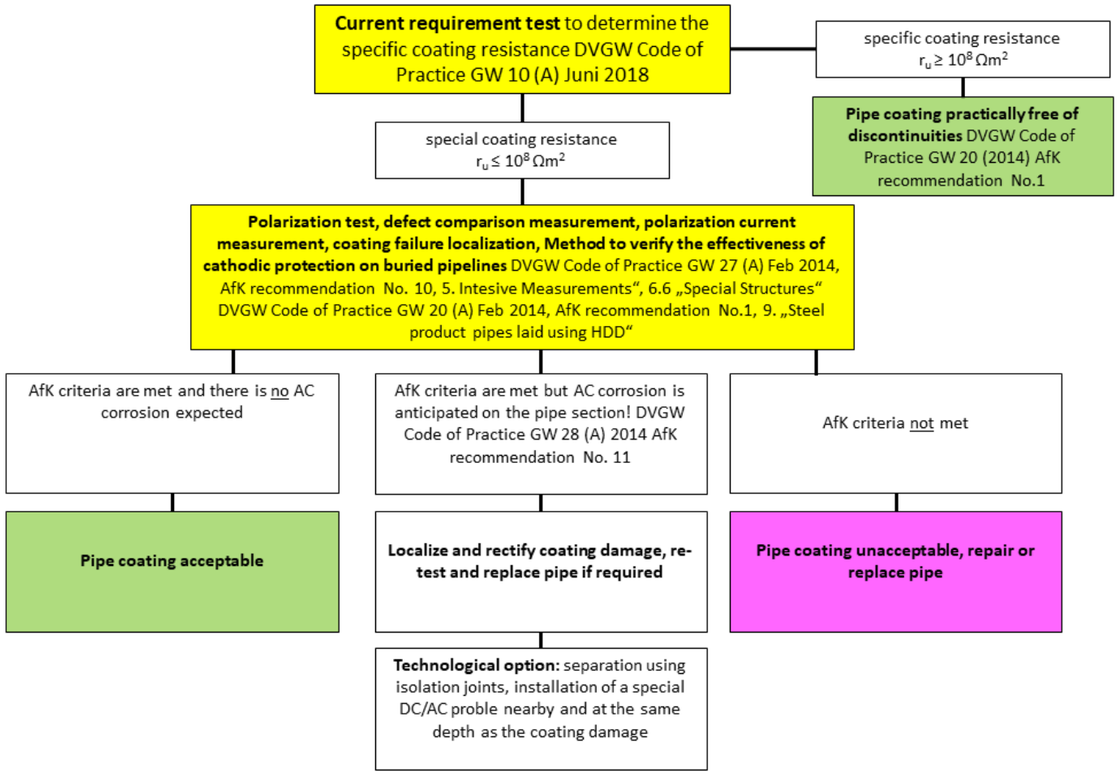

Figure 2: Testing the coating of pipelines laid using HDD

When laying pipelines in so-called „energy routes" in close parallel with high-voltage overhead lines (AC) and the resulting inductive high-voltage interference, smaller coating defects should be considered critical in terms of the risk of AC corrosion. The associated risk for the pipeline must be assessed based on the operating data of the influencing AC system, especially when considering the potential effects of the resulting induction.

6.3.2 Current requirement test to determine the specific coating resistance

After the bottom hole assembly has been removed from the pipeline following pullback, the procedure for determining the specific coating resistance will be repeated on the entire pipe string, as was done during the electrolytic holiday detection. However, an electrically conductive electrolyte such as bentonite mud must be used in the borehole, and a temporary auxiliary anode must be installed in an external, neutral position.

This will allow the accurate measurement of the coating resistance, while avoiding errors due to leakage and stray currents. The measurement must be carried out with precise, suitable measuring devices that consider any potential circuit errors.

If the required coating resistance is not achieved, despite efforts to ensure a defect-free coating of the pipe string, a polarization test is necessary, as shown in Figure 3.

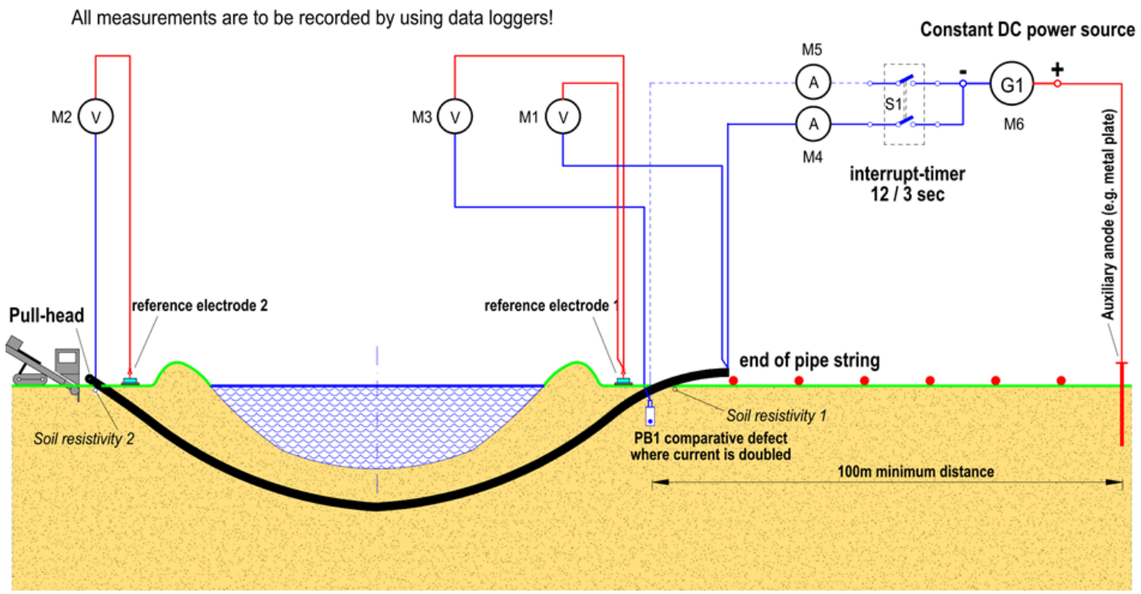

Figure 3: Overview of set-up for polarization test

6.3.3 Polarization test to examine cathodic polarizability

The polarisation test involves the following examinations, as per Afk 1 and Afk 10 (February 2014):

- Assessment of cathodic polarisation capability
- Defect comparison measurement through current doubling
- Polarisation current measurement
- Defect location

Using a specialized targeted protection current, directed onto the pipeline under test against a neutrally positioned auxiliary anode, the above parameters are recorded in detail and evaluated. The required cathodic polarisation capability of a present coating damage should be significantly assessed through this examination.

However, if a corrosive alternating current interference is expected to occur on the pipeline, then the coating damage must be located and repaired, or other measures taken, such as insulated separation points and targeted AC boundary

devices, even if the polarisation criteria are met.

During defect location, the pipeline is disconnected from the ground at the ends, and an injection is made against a neutrally located auxiliary anode. The pipeline potential should be significantly increased for defect location, depending on the soil covering to make the voltage funnel generated by the current entering the coating defect into the ground clearly detectable. The location is then performed and recorded at 1 m intervals along the measured pipeline route.

The method described is generally equivalent to the intensive measurement method, which, however, can only produce reliable results for up to a maximum of two meters of soil covering.

Application Note:

If, despite all efforts to locate and repair the defects, the minimum criteria for polarisation capability of the pipeline specified for the project are not met, the coating is unacceptable. The pipeline must be repaired or replaced. Alternatively, the operator may accept limitations on the operating parameters and/or service life.

More detailed information on the methods for demonstrating the effectiveness of cathodic corrosion protection for buried pipelines can be found in the specific technical guidelines and standards of each country.

7 Available coating systems

7.1 General information

The project-specific selection of a coating system, along with an additional mechanical protection such as a wear layer, is crucial for successful installation of a pipeline using the HDD method. The coating must meet the highest quality standards in terms of materials and the expertise of the personnel performing the installation due to the often-demanding conditions of the borehole. The guidelines provided by the coating system manufacturer, particularly those relating to climatic conditions, must be strictly followed. In addition, the thickness of the field-applied weld coating must not exceed that of the original factory coating. It is important to ensure that the surface of the recoated weld is flush with the plant-applied coating, which should be considered during the planning stage of the corrosion protection system.

The quality of the selected coating system, along with knowledge of the subsoil geology in the drilling route area, is a decisive factor in achieving a defect-free installation.

7.2 Factory coatings

7.2.1 General information

Mechanical damage is a common cause of defects in pipeline coatings during onshore construction, particularly in the case of trenchless pipe installation. Therefore, pipeline coatings must possess mechanical resistance or require additional mechanical protection in order to avoid or minimize the effects of impacts. These requirements should be addressed, whenever possible, at an early stage in the pipeline design and construction process to ensure the corrosion protection system(s) perform as intended, ensuring long-term pipeline integrity.

Most commonly used external anti-corrosion coatings, whether applied in the field or at the plant, already contain some basic level of mechanical resistance. Multi-layer coatings have been developed to enhance the basic mechanical resistance. Despite the use of high-quality and site-specific materials, it is still possible for coating damage to occur during HDD installation due to unfavorable ground conditions such as sharp rocks in the soil.

The industry‘s most commonly used systems are described in the following subsections. Note that the list of systems presented here is not exhaustive, as other systems such as liquid polyurethanes are also used in HDD pipeline projects but to a limited extent.

7.2.2 Polyolefin coating systems (PE/PP)

7.2.2.1 Polyethylene coatings (PE)

According to DIN 30675 part 1, polyethylene-coated pipelines provide corrosion protection that is effective even in extremely aggressive soils of soil class III. The current three-layered system typically includes a primer and adhesive film, as well as a tube-extruded polyethylene layer depending on the pipe diameter in the relevant section.

DIN EN ISO 21809-1 standardizes the use of PE coatings for oil and gas pipeline transportation systems. However, for other fields of application, such as pipelines for gas distribution and water supply or for smaller projects, the rules and regulations in Germany are laid down in DIN 30670.

While PE coating systems may be suitable for horizontal directional drilling to a limited extent, they may only be used in uncritical soil conditions. In such cases, it is recommended to use at least the reinforced coating thicknesses (r) according to Table 2 or thickness class 3 according to Table 1. The all-purpose coating thicknesses can also be found in Table 1 and Table 2.

Table 1: Minimum coating thicknesses (depending on diameter) according to DIN EN ISO 21809-1

Thickness class	**1**	**2**	**3**
Soil conditions	sandy soil onshore	clay soil without backfill material	stony soil * and offshore
Class A (up to 60°C)	1,8 – 3,2 mm	2,1 – 3,8 mm	2,6 – 4,7 mm
Class B (up to 80°C)	1,3 – 2,5 mm	1,8 – 3,3 mm	2,3 – 4,2 mm

*Regardless of the coating thickness, rock-free (open trench) installation is crucial, especially in rocky and stony soils.

Table 2: Minimum coating requirements for polyethylene coatings according to DIN 30670

Pipe diameters	Minimum thickness (mm)	
	normal (n)	reinforced (r)
up to DN 100	1,8 mm	2,5 mm
from DN 100 to DN 250	2,0 mm	2,7 mm
from DN 250 to DN 500	2,2 mm	2,9 mm
from DN 500 to DN 800	2,5 mm	3,2 mm
from DN 800	3,0 mm	3,7 mm

7.2.2.2 Polypropylene (PP) coatings

In comparison to polyethylene (PE) coatings, polypropylene (PP) coatings are mechanically more resilient and are commonly used in applications with higher operating temperatures, as well as in trenchless construction methods such as horizontal directional drilling. However, PP coatings are susceptible to embrittlement at low temperatures (<0°C), which can result in damage during installation. The layer structure and manufacturing process of PP coatings are identical to that of PE coatings. While the requirements for oil and gas transport pipelines are specified in DIN EN ISO 21809-1 for both types of coatings, the national standard for PP coatings in Germany is DIN 30678. Information on the range of coating thicknesses specified in the regulations for PP coatings can be found in Tables 3 and 4.

Table 3: Minimum coating thickness (depending on diameter) according to DIN EN ISO 21809-1

Coating Thickness Class	1	2	3
Soil properties	Onshore sandy soil	Clay soil without backfill	Stony soil * and offshore
Class C (PP)	1,3 – 2,5 mm	1,7 – 3,0 mm	2,1 – 3,8 mm

*Regardless of the coating thickness, a rock-free (open-trench) installation is crucial, especially in rocky and stony soils

Table 4: Minimum coating thickness for polypropylene coatings according to DIN 30678

Pipe diameter	Minimum thickness (mm)
<= DN 100	1,8 mm
> DN 100 und <= DN 300	2,0 mm
> DN 300 und <= DN 500	2,2 mm
> DN 500	2,5 mm

7.2.3 Multi-layer and thick-coating systems

7.2.3.1 Thermoplastic multi-layer and thick-coating systems

There are two types of special polyolefin coatings for horizontal directional drilling (HDD): thick coating systems made of polyethylene or polypropylene, and multi-layer systems that combine different extrudable plastic layers.

In the tube extrusion method, the layer buildup usually takes several extrusion iterations. On the other hand, winding produces thick-coating systems made of polyethylene or polypropylene in a single stage process.

The main factor that determines the categorization between the two types of coating systems is the production speed. In the case of smaller pipe diameters, the relatively slow cooling time of the coating, especially for thick-coating systems, increases the risk of uneven coating thicknesses due to the pipes being transported via rollers along the production line. Therefore, the coating layers are built up in several iterations. Using the same material for all iterations ensures that all layers are welded together and form a homogeneous layer structure.

The primary drawback of a welded thick-coating system is that any cracks in the coating will extend to the base material. However, a multi-layer structure can be designed to prevent this by using two different coating materials that lack adhesive strength between layers. Typically, a mechanically resistant material such as polypropylene or polyamide is used as the outer layer, while the corrosion protection is provided by a polyethylene coating underneath. Polyamide is preferred over polypropylene due to its greater hardness and better resistance to cold and cracking.

The polyethylene layer is usually manufactured using a multi-layer system with a rough coat design, which provides the required shear strength of the coating due to its rough surface structure (see Figure 4).

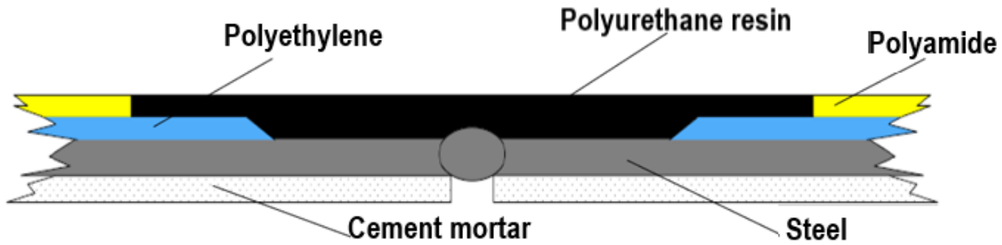

Figure 4: Schematic representation of the layer structure of a multi-layer system in the pipe connection area.

Because these multi-layer systems are executed as one thick layer, grouting systems can also be used for field-applied coating of pipe connections. However, it is important to ensure that the ends of the coating overlap sufficiently to provide corrosion protection and prevent any protrusion of the field applied coating material that would affect pipe pullback.

7.2.3.2 Fiber Cement Mortar (FCM) – coating

Fiber Cement Mortar (FCM) coating specifications for Germany are described in DVGW worksheet GM340 and DIN 30340-T1. There are two types of FCM coatings:

- Pipes for open-trench installation: The FCM coating is directly applied to the PE coating (type N according to DVGW worksheet GW 340). There is no adhesion between the polyethylene coating and the mortar layer.
- Pipes for trenchless installation: Adhesion of the FCM coating is realized with an adhesive agent or rough coating of the underlying polyethylene (type S according to DVGW worksheet 340).

FCM-S coatings have been utilized in trenchless pipe installation since the 1990s, primarily for pipe sizes up to DN 600. These coatings allow for the versatile application of pipes and can also serve as an additional protective measure in rocky soils. FCM coatings have also become increasingly relevant in special projects, such as inverted siphon installation or installations at sea. However, it should be noted that FCM coatings according to DVGW worksheet 340 should not be confused with concrete casing according to DIN EN ISO 21809-5, which is designed to provide the necessary downforce for offshore pipeline installations and cannot be used for horizontal directional drilling.

Figure 5: FCM sheathing production

The FCM coating is composed of dried quartz sand, cement, water, fibers, and other aggregates. Prior to the application of the coating onto the corrosion protection layer, a second holiday test is conducted with a voltage of 25 kV to ensure there is no damage. The mortar is applied to the rotating pipe in a spiral pattern using a slotted nozzle. Additionally, a tear-resistant plastic fabric bandage is integrated into the cement mortar with an overlapping design. Finally, the mortar layer is mechanically smoothed to achieve the desired finish (see Figure 5).

The minimum coating thickness is 7 mm and is produced in tolerances which, if necessary, permit the bending of cement mortar coated pipes with the bending equipment usually available on site (see Figure 6). The generally limiting factor to elastic bending of a steel pipe string for HDD installation is the maximum permissible bending stress of the pipe material.

Figure 6: Bending of FCM coated pipes

The required shear strength of the S design for trenchless construction is achieved by rough coating the polyethylene coating. For this purpose, the polyethylene coating is extruded in a T-shape in a longitudinal direction and additional coarse polyethylene particles are melted onto the hot material. Regardless of the direction of acting forces, a mortar layer fixed in this way must be destroyed in order to separate it from the polyethylene coating. The last 2 to 3 centimeters of the rough coated pipe ends are not covered with cement mortar so that any field applied coating with casting mortar or a polyurethane grout can mechanically interlock at the intersection with the existing mortar coating (see Figure 7).

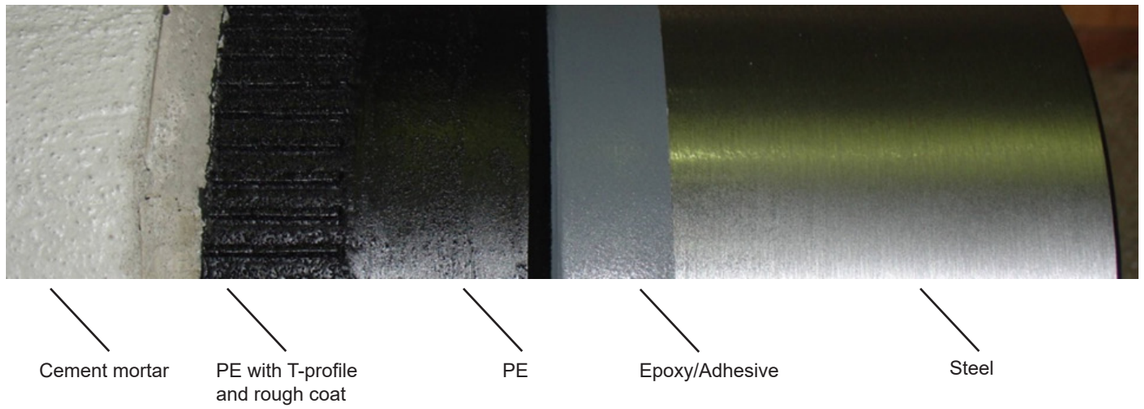

Figure 7: Pipe ends with FCM-S type

7.2.3.3 Glass-reinforced plastic (GRP)

Glass-reinforced plastic (GRP) is a composite material with high mechanical strength and chemical resistance. Due to its properties, it has been applied successfully as additional protection for plastic-coated steel pipes since the mid-nineties. The most common materials for GRP coating are unsaturated polyester or vinyl ester resins without fillers. These resins, together with durable textile glass fiber mats and/or roving yarns, are wound onto the corrosion protection layer, which usually consists of a 3LPE/3LPP coating. The curing of the resins can be realized with UV light or thermal curing by the addition of peroxides.

Figure 8: GRP factory coated pipes DN 700 – ready for HDD crossing

The established shear strength for GPR coating is ≥ 100 N/cm² which is achieved by machining the surface of the corrosion protection coating before winding. Furthermore, an insulation test of the pipe surface is performed before winding to ensure the integrity of this coating. The thickness of the GRP coatings is usually at least 5 mm but can be adjusted to suit specific project requirements.

In accordance with customer specifications or project requirements, GRP skids can be applied to the GRP coating during winding, e.g., for pipe pull-in into protective pipes.

7.3 Field applied coatings

7.3.1 General information

The following chapters present the field joint coating systems that are most commonly used in the industry. However, note that the list of systems described below is not comprehensive, as other systems may also be used in HDD pipeline projects, albeit to a lesser extent. When planning, it should be taken into consideration that a smooth and even surface is achieved by combining the factory coating and field joint coating.

7.3.2 PUR and PUA – Coatings made of polyurethane PUR and polyurea PUA

Polyurethane and polyurea coatings consist of a duroplastic material that forms a stable three-dimensional molecule grid upon curing. This is in contrast to thermoplastic polyolefinic, bituminous systems, or those based on petrolatum. As a result, polyurethane or polyurea-based systems exhibit high strength against mechanical and thermal stress, as well as good chemical resistance. These properties, combined with specific processing techniques, define the broad range of applications, such as mill coating and field joint or field applied coating of pipes, fittings, and valves (see Figure 9).

Figure 9: Pipeline with field joints protected by polyurethane PUR

There are only limited standards dedicated for the use of these coatings in the field of HDD that describe the requirements of a duroplastic system, here polyurethane or a polyurea coating. The standards that are used to describe the specifications of polyurethane coatings are the following:

- DIN EN 10290 - Steel tubes and fittings for onshore and offshore pipelines - External liquid applied polyurethane and polyurethane-modified coatings
- DIN EN ISO 21809-3 - Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 3: Field joint coatings
- DIN 30672-1 - Backfill materials for corrosion protection of buried pipelines - Part 1: Requirements and product testing.

Please note that there is no specific standard for polyurea coatings for use in HDD applications.

When using polyurethane as a field joint coating for HDD, the application of the polyurethane coating via injection in a mold has been shown as best practice. Here, the coating is provided from a two-chamber cartridge by a semi-automatic injection in one work step in a special mold system (see figure 10). By this technique, easy scaling up and down with respect to the field joint area and pipe diameter, as well as the required dft, is possible, thus providing a homogeneous system. The mold system provides a high surface quality and protects the material against weather impacts during hardening. In such a way, applied field joint coatings are in-line with the mill coating independent of the specific dimensions.

Figure 10: Injection of the polyurethane into the casing sheet with the special two chambers cartridge

7.3.3 GRP weld coating on site

There are different methods for applying glass-reinforced plastic (GRP) coating to welds on site, as shown in Figure 11. High-quality polyester or vinyl resin systems, both light-curing and peroxide-curing, as well as epoxy-based reactive resin systems, are used. The glass mats are applied by hand-winding, saturated with sufficient resin, and according to the manufacturer‘s specifications. For HDD applications using polyester or vinyl ester resin systems, a suitable corrosion protection system (e.g., PE/butyl tapes, PUR or heat-shrinkable materials) should always be applied under the additional mechanical protection.

In all applications, the manufacturer‘s process instructions must be followed. Ambient conditions such as temperature, humidity, and UV radiation (daylight/sunlight) can significantly affect the quality of the coating. When selecting UV lamps and preparing the resin mixture on site, the manufacturer‘s specifications must be followed. If applicable, additional work instructions from the network operator must be followed for post-application GRP weld coating. The compatibility of the resins used with the factory-applied GRP coating is fully assured between the different resins and curing methods mentioned here, as well as with the typical polyolefin factory coatings (PE and PP).

To prevent the creation of a local point of increased mechanical stress in the field joint coating area, it is necessary to avoid raising the height of the weld coating above the factory coating. The generated shear strength between the factory coating and the additional mechanical protection should be tested in accordance with DVGW GW 340 or DIN 30340. If shrink or tape materials are used below the GRP layer, there is no shear strength, and the relevant test is not applicable in this case.

DIN 30340 provides a technical standard describing the application of GRP field applied coating as mechanical protection in trenchless pipe installation.

GRP systems based on vinyl ester and epoxy resins are only described for corrosion protection purposes in DIN EN ISO 21809-3.

Figure 11: Additional coating of the weld with GRP

7.3.4 Shrink Sleeves

Shrink sleeves are commonly used in pipeline construction to protect girth welds against corrosion, typically applied on FBE- and PP-coated pipes. However, the standard sleeve does not provide sufficient mechanical protection required for use in HDD.

For HDD applications, special versions of the sleeve are available that are fabricated from a thick, irradiation cross-linked, thermally stabilized, fiberglass reinforced, heat-shrinkable woven polyolefin backing, coated internally with a hot-melt adhesive. Adhesion to bare steel pipe surfaces is enhanced by applying an epoxy primer. During installation, the epoxy is applied to the prepared pipe surface and the heat-shrinkable sleeve is immediately wrapped around the joint over the wet epoxy. Heat is then applied to the sleeve, causing it to shrink and form a tight fit around the joint. A low-profile closure patch is used to close the sleeve and provide the strength to withstand the shrink forces during installation.

Figure 12: Field-Joint Coating "DIRAX-System"

Figure 13: Construction "DIRAX-System"

A wear cone of the same material as the main sleeve is then applied over the leading edge of the sleeve. It is important to note that the use of shrink sleeves for HDD applications is limited to certain pipe diameters and favorable soil conditions. For more information, see figures 12 and 13.

7.3.5 Cement Mortar coatings

The field joints of cement mortar-coated pipes must be provided with a corrosion protection system according to DIN EN 12068 since the cement mortar provides only mechanical protection. To ensure that the field joint has the same level of mechanical protection as the factory-coated pipe, cast mortar coating systems can be used. The cement mortar used for this application has a composition specifically adapted for the purpose, containing plastic fibers and meets the requirements of DVGW GW 340 and DIN 30340 T2.

For the application of the cast mortar system, formwork is used to ensure a continuous transition between the factory coating and the field joint coating. The mortar is mixed according to the manufacturer's instructions and poured into the formwork. The formwork is left in place on the pipe to allow for proper curing of the cast mortar system and can be removed before pullback (see Figure 14).

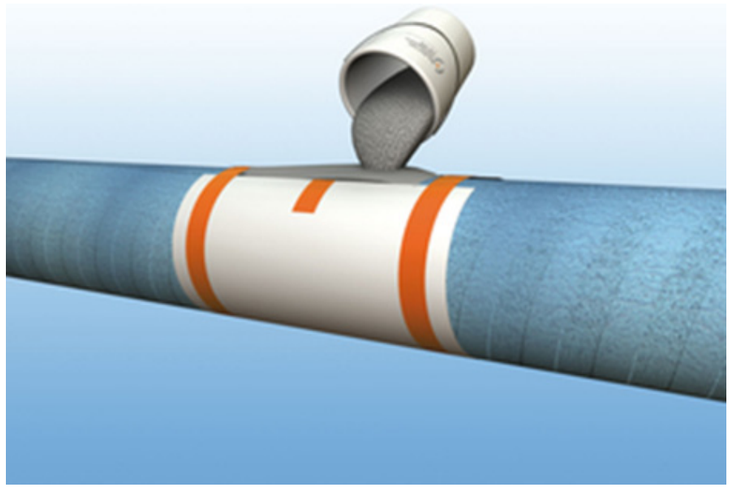

Figure 14: Post-coating weld area with FCM.

8 Complexity of HDD projects

8.1 General information

As emphasized in previous chapters, there is a wide variety of coating materials and systems available for HDD projects. These materials can be combined in different ways and adjusted to meet specific project requirements, such as coating thickness and number of layers, as well as individual preferences of the pipe operator based on their expertise.

The individual requirements of each project are determined by factors such as the project environment, including subsoil conditions and temperature and chemical influences from groundwater and subsoil. The impact of these factors on the pipe coating depends on the geometric properties of the borehole and pipeline. The more influence and degree of stress from borehole geometry, the more complex the interaction and stress on the pipe coating.

The following sections present a categorization of different levels of complexity based on empirical data and experience, which can serve as a rough guideline for assessing project-specific requirements.

8.2 Drilling parameters

8.2.1 General information

The HDD technique involves the final step of pulling a product pipe back into the drilled/reamed hole. This step exposes the product pipe coating to various physical loads such as friction, stress due to overbending, and others. Therefore, the different drilling parameters can have a significant impact on the condition of the coating after the pullback.

Table 5 below summarizes the main parameters that should be carefully considered before and during the pullback:

Table 5: Drilling parameters

Parameter	Complexity		
	Low	Medium	High
Pipe buoyancy in fluid	< 500 N/m	500 – 2.000 N/m	> 2.000 N/m
Length	< 500 m	500 - 1.000 m	> 1.000 m
Pipe diameter	< 10" (250 mm)	10 - 24" (250 - 600 mm)	> 24" (600 mm)
Hole diameter	< 16" (400 mm)	16" - 32" (400 - 800 mm)	> 32" (800 mm)
Radius in borehole [(1)]	> 1,1 x R_{design}	0,9 – 1,1 x R_{design}	< 0,9 x R_{design}
[(1)]Note: R_{design}: Calculated design radius acc. to DCA guidelines			

8.2.2 Pipe buoyancy

The uplift or drag of the product pipe in the borehole is one of the most crucial parameters, as greater force results in higher frictional forces and potential damage to the coating.

For a steel product pipe with a diameter larger than 30 inches, it is customary to weight the pipe during installation to reduce its buoyancy inside the borehole. Different ballasting systems can be utilized in such circumstances:

- Weighting is generally done by pumping water from the tail of the product pipe during installation, which provides accurate control of the added weight and avoids any mechanical damage to the pipe‘s interior:
  - Completely filling the pipe with water generally leads to strong negative buoyancy. This can be counteracted by increasing the weight of the drilling fluid before installation, which raises the positive buoyancy and decreases the overall buoyancy of the pipe.
  - Alternatively, the inside of the pipe can be partially filled with water to attain nearly neutral pipe buoyancy. This option is very efficient, but it is also quite expensive since it involves installing temporary pipes inside the main steel pipe and filling them (or their annular space) as the installation progresses
- Another option is to add weights inside the product pipe before installation, which also results in a perfectly neutral pipe. This method is used less often because of the risk of damaging the pipe while inserting or removing the weights and because additional weights have to be lifted by cranes in the overbent section, something that is avoided when pumping water.

For further technical details on ballasting, please refer to chapter 7.3.4 of the DCA Technical Guideline (4th Edition - 2015).

8.2.3 Drilling length

The intensity of the friction acting on the first section of the product pipe after the pulling head is directly proportional to the length of the borehole. The longer the borehole is designed, the greater the distance and duration during which the front end of the pipe is exposed to this friction.

8.2.4 Borehole diameter and shape

The diameter of the product pipe is directly related to the required borehole diameter. According to the DCA Technical Guidelines, the acceptable ratio between these two diameters generally ranges from 1.2 (for stable ground conditions and low friction) to 1.5 (for unstable ground conditions and high friction).

When using a multiple-stage reamer, optimal centralization can be achieved during the second and subsequent widening phases. This prevents the creation of a keyhole or oval-shaped borehole, which could potentially cause more friction on the product pipe than a perfectly round borehole.

For the insertion of bundles of pipes into a borehole, the ratio between the diameter of the product pipe and the required borehole diameter should be determined on a project-specific basis.

8.2.5 Bending radius

The bending radius of the pipe inside the borehole can also be an important parameter. The effect depends on the type of coating used and the soil conditions encountered. The DCA technical guidelines provide detailed instructions on how to calculate the minimum radii that must be respected when planning an HDD operation.

8.2.6 Drilling fluid circulation

Maintaining a continuous drilling fluid circulation is crucial for HDD operations. During product pipe pullback, drilling fluid is continuously injected through the drill string and enters the hole via the bottom hole assembly, which is set in front of the pulling head.

Drilling fluid plays a significant role in HDD operations, especially in lubricating the annular space around the product pipe during pullback. However, in very permeable formations such as sand and gravel or fractured zones like karst or weathered zones, drilling fluid may be lost in the formation, resulting in poor or minimal lubrication around the product pipe. This can cause additional abrasion on the coating due to increased friction between the pipe and the drilled hole.

Therefore, it is crucial to pay particular attention to drilling fluid circulation during HDD operations, as per the DCA technical guidelines.

8.2.7 Borehole cleaning

Borehole cleaning is mainly achieved through the circulation of drilling fluid, which transports the ground cuttings out of the hole and up to the surface.

If the hole is not adequately cleaned before pullback operations, it may lead to an increase in required pull force due to poor lubrication. The annular space around the product pipe may be filled with ground cuttings, preventing the necessary circulation of the drilling fluid. Additional abrasion on the coating would then occur due to the increase in friction between the pipe and the drilled hole.

Therefore, the borehole must be sufficiently cleaned before proceeding with pullback operations. If necessary, additional cleaning runs should be executed, as per DCA technical guidelines.

8.2.8 Borehole obstruction

During the pilot bore or reaming process, if for example an anthropogenic borehole obstruction, such as a foundation or an old pipeline, is encountered, consideration must be given to whether the obstruction may damage the product pipe during pullback.

<u>Application note:</u>

In such cases, an emergency plan should be developed. Completely circumventing the obstruction and altering the bore path is one possibility. The decision can only be made on a project-specific basis.

8.3 Pipe pullback conditions

8.3.1 Pipe rollers

Most coating damage during HDD pullback operations is directly related to the situation downhole, although aboveground influences can also occur that affect the quality.

Special attention should be given to pipe roller alignment and setup, especially when dealing with very stiff pipes. Incorrect leveling of the rollers may cause uneven loading, with some rollers bearing more weight than others. This not only damages the overloaded rollers but can also cause coating damage.

A roller that does not turn during pullback can also damage the product pipe coating. For these reasons, the pipe must be checked immediately before entering the hole. A holiday detection and visual inspection by the operator are mandatory, and pullback must be stopped in case a coating defect is found until it is repaired and the pipe is ready for pullback.

8.3.2 Catenary design

The catenary, also referred to as the overbend or launching ramp, is the curve of a section of the product pipe just before it enters the drilled hole during pullback. Generally, the product pipe is lifted by cranes or positioned on elevated roller supports, which must be strong enough to handle both the weight of the pipe and the vertical and horizontal forces. If cranes are used, they must also be equipped with cradles to support the lift force and to prevent any damage to the steel pipe during progression.

Depending on the type of coating being used, the bending radius of the pipe inside the catenary may also be an important factor; the DCA technical guidelines provide detailed information on how to calculate the minimum radii that should be respected. Special care must be taken when coupling horizontal and vertical radii as the horizontal radius must often be considered to ensure the correct alignment of the pipe with the drill path.

The values listed in table 6 are reference values: a minimum of 800 x ND in the overbend section, below which specific calculations and individual consideration must be given.

Table 6: Radius in overbend

Parameter	Complexity		
	Low	Medium	High
Radius in overbend [1]	> 1.000 x DN	1.000 x DN – 800 x DN	< 800 x DN
[1]Note: DN: pipe nominal diameter [m]			

8.4 Geologie

As previously mentioned, the coating is subjected to downhole frictions when the product pipe is pulled into the hole. Therefore, the geological conditions along the route, i.e., the ground conditions, play an important role.

Table 7 below summarizes the main geotechnical parameters that may be relevant when selecting the coating for an HDD project:

When selecting the coating (type/thickness), the actual geotechnical conditions must be taken into account. The worst-case scenario should always be considered, and the coating should be designed accordingly. For example, when drilling through chalk with flints, the coating should consider the presence of flints.

In general, the coating must provide sufficient resistance against the ground to meet the minimum requirements for the functionality of the corrosion protection system after installation. Critical soils or layers should generally be avoided as much as possible through proper drilling planning. However, as this is often not possible for the entire drilling alignment, the remaining critical layers must be considered when selecting an appropriate coating system.

Table 7: The main geotechnical parameters when selecting the coating

Parameter	Risk	Mitigation measures
Abrasiveness	The abrasiveness of the ground can lead to local damages or excessive wear on the coating reducing the coating thickness.	Choose the appropriate coating hardness and thickness consider-ing geotechnical characteristics of the most abrasive element to be drilled (e.g., flint when drilling in chalk).
Weathering degree Fragmentation Fissuration	A weathered rock will not easily produce a smooth internal hole wall, which may lead to have a sharped stone / block damaging the coating during the pullback (scratches / cracks)	Proceed with cleaning runs and if needed increase the reaming diam-eter and/or pull a trial coated sec-tion prior to pullback to assess potential damages.
Big stones Blocks	A big stone or a block may also lead to coating damages (same process than above)	Proceed with cleaning runs and if needed increase the reaming diam-eter and/or pull a trial coated sec-tion prior to pullback to assess potential damages.
Gravels	Pulling a steel pipe through gravel layer is never easy because of un-stable hole: if sharp and abrasive gravels are in contact with the coat-ing, a damage may occur.	Avoid or treat gravel layers accord-ing to DCA Technical Guideline

8.5 Chemical influence of soil and ground water contamination

The coating systems currently in use are suitable for all types of natural soils in accordance with applicable standards. The barrier effect of coatings against corrosive substances such as chlorides, water, and oxygen remains unaffected by the composition of the surrounding soil.

However, when it comes to trenchless pipe-laying methods, some special considerations need to be made. The mechanical properties of plastic coatings may be influenced in soils with absorbed hydrocarbon content. The reduction in material hardness, and thus resistance to indentation, affects the mechanical strength and integrity of the coating system under service conditions. The application of additional layers is especially important as they provide improved mechanical protection not only during pipe string installation, but also under service conditions. The tendency of standard mill coatings for buried pipelines with regard to their capacity for hydrocarbon absorption can be ranked in the following order:

PE > PP > FBE, PA, GRP, FCM

Materials such as PA, GRP or FCM are particularly suitable as base materials for protective coatings.

One aspect to consider in hydrocarbon-contaminated soils is the potential reduction in mechanical strength, especially with regards to point loads in the area around a well. In addition to the impact of hydrocarbons, it is also important to consider the embrittlement of the coating due to ageing. However, as long as the pipeline is bedded according to the applicable specifications and no additional point loads occur, this embrittlement is irrelevant for the barrier effect of a corrosion protection coating layer. Depending on the type and composition of the soil, mechanical impacts during pipe string pulling must be taken into account. The scratches and notches resulting from this operation can promote the formation of cracks in the corrosion protection layer of the coating in the event of ageing-related embrittlement. In such cases, short-term tests with surfactants are not significant; although they may provide useful information about a new coating, they do not take into account the ageing process of a coating. In addition, where crack formation initiated by scratches and notches necessarily only affects the outer coating layer, additional coating layers for mechanical protection are preferable.

Furthermore, there may be other potential pollutants in the soil for various reasons, which can have an impact on the coating during the pipeline‘s lifetime, and these must be considered when selecting the coating system.

9 System selection based on complexity

When selecting the necessary protective systems for a specific construction project, the choice of the appropriate field-applied coating must be taken into account. The different coatings and coverings are only partially compatible with each other and require careful consideration even in the planning stage to avoid errors during later execution (factory coating and field-applied coating).

Monolayers (PE, PP, FBE) with standard coating thicknesses are applied directly to the steel and provide only limited protection against mechanical damage during trenchless installation. The field-applied coatings used can provide protection against damage only to a limited extent, if at all.

Monolayers made of thick PE or PP coating systems or multilayer systems are better suited for trenchless pipeline installation than monolayers with standard coating thicknesses. The choice of the correct combination depends on site-specific factors that lead to different levels of complexity, as described in the previous chapters. Table 8 below shows a selection of recommended coating system combinations depending on the complexity.

Table 8: Selection of recommended combinations of coating systems depending on complexity

Factory coatings		Field applied coatings	Project complexity
Thick-coating sys-tems	PE und PP standard	Heat shrinkable material (reinfor-ced) Polyurethane	low
	PE or PP thick-coating system	Polyurethane	medium
Material combination	Combination PE/PP		
	Combination PE/PA	Polyurethane	high
	Combination PE/FCM		
	Combination PE/GRP	Combination heat shrinkable material or corrosion protec-tion with GRP, PUR, or cement mortar grouting	

10 Risk Influenceability

This chapter summarizes the potential aspects that can influence the quality and efficiency of the coating. The term „risk“ is used throughout, although it partially refers to the term „hazard“.

Attachment 1 describes the most common factors that influence the integrity of the pipe coating during HDD installation. These factors can individually or in combination lead to damage.

The Risk Influenceability matrix (Attachment 2) assigns a risk factor of 1 to 4 to each coating parameter, with 1 being minor and 4 highly critical. It also assesses how each project stakeholder (HDD contractor, pipeline contractor, planner, and owner) can influence the parameters. This is to make each party aware of its individual responsibility and show where, when, and who needs to take leading action to ensure the final integrity of the coating after installation.

The second matrix (Attachment 3) enables a project-specific risk assessment that can be completed and adapted for each specific project. The described factors in column 1 need to be reviewed and, if necessary, supplemented. Assessments need to be made in columns 3 and 6, and measures to reduce or avoid risks need to be reviewed, adapted, and added in column 5.

The parameters identified in the matrix in Appendix 3, and described in the separate explanation of the table, can individually or in combinations cause damage. Each one must be carefully evaluated when designing the coating

11 Use of a Conduit

If, despite all mitigation measures, it is not possible to sufficiently minimize or reduce the risk of damaging the coating, installing an additional larger conduit into which the product pipe is pulled may be a possible solution. Depending on the project conditions, this may be applied over the entire length or only a part (at the ends) of the horizontal borehole.

In this method, the additional conduit alone absorbs the stress that could cause damage to the coating. Therefore, the conduit must be designed to take into account potential damage during installation, such as scratches to a possible coating and/or wall thinning (especially when using HDPE).

Using such a conduit also requires a complete redesign of the borehole with regard to borehole diameter, drilling radii, drilling length, and coating system, among others. Additionally, its impact on the active corrosion protection system should be investigated and evaluated.

12 Conclusion

The DCA Technical Info No. 6 with the topic “Pipe casing and coating in HDD” provides an overview of commonly used coating systems for steel pipe installation in Europe, including corrosion protection and mechanical protection, for both factory and field application in the weld area (recoating). The complexity of the subject matter is evident from the multitude of materials and possible combinations available, making it crucial to carefully examine and consider the relevant properties and operating conditions in the planning stage of a pipeline project. Even high-quality work on the pipe and installation on site cannot compensate for early misjudgments and wrong estimations in terms of specific project requirements, which may have lasting consequences for the service life of the HDD-installed steel pipeline.

If a suitable material has been chosen, the handling and processing of the pipes and coating materials are crucial for the quality and integrity of the pipe coating. However, field-applied weld coatings on site are often a source of damage or impairment to the corrosion protection system if errors or carelessness occur during their application. To minimize this risk, it is recommended to use trained coating personnel who are familiar with the manufacturer‘s processing instructions, and to provide additional qualified supervision of the coating process. Quality assurance for welds is a reference for the overall coating process, and follows a similar procedure: certified welders and a certified welding supervisor are responsible for ensuring the required weld seam quality.

When it comes to coating, a similar quality assurance system is used for weld seam production, where certified welders and a certified welding supervisor are responsible for ensuring the required weld seam quality.

Similarly, in the area of coating work, some pipe network operators are increasingly using a „coating inspector“ to oversee the coating work on site.

Coating personnel must have the appropriate training and certification for the specific coating material being used, as well as extensive experience, specific training, and instructions so they are familiar with the special requirements for coating quality in trenchless installations. Coating quality that is sufficient for open-trench installation may be insufficient given the additional mechanical stress of a trenchless installation.

Lastly, the HDD contractor is responsible for creating a borehole suitable for pipe pull-back. Doglegs, insufficient ballasting of the pipeline, and other factors can cause unnecessary stress on the coating. It is the drilling company‘s responsibility to ensure the proper condition of the borehole (such as the absence of stones and the creation of a smooth wall) before pullback.

13 Attachments

Attachment 1: Explanation: risk matrix tables

Attachment 2: Risk influence matrix for quality and efficiency of steel pipe coatings

Attachment 3: Risk assessment matrix (exemplary project-related risk assessment)

Attachment 1 Explanation of risk assessment

Below are described the most common influencing factors in connection with the integrity of the pipe coating during a pullback in an HDD borehole. The influencing factors can lead to damage in combination or individually.

Subsoil

Abrasion

- High abrasiveness leads to material abrasion on the protective system.

Degree of weathering/fragmentation/fissuring

- Fissures and weathered rock may have sharp-edged fracture surfaces that can peel or slit the protective system.

Large stones/blocks

- Can cause high point loads due to their own weight or wedging in the borehole, leading to peeling or indentation of the protective system.

Sharpness of fracture surfaces/edges

- Sharp-edged fracture surfaces can peel or slit the protective system.

Cavities

- Can cause loss of drilling fluid, leading to reduced lubrication and thereby to abrasion.
- Larger cavities can cause high point loads if the pipeline does not rest on the edges of the cavity over a longer distance.
- They can also lead to deflection of the pilot bore and thus to so-called dog legs, which in turn cause high point loads and/or excessive bending.

Gravel

- Can cause loss of drilling fluid, leading to reduced lubrication and thereby to abrasion.
- Can also cause deflection of the pilot bore and thus to so-called dog legs.
- Unstabilizable gravel can cause (partial) borehole collapses and, as a consequence, increased friction and abrasion

Material Selection

Selection of factory coating

- The resistance and/or hardness of the factory coating must be adapted to the anticipated geotechnical conditions. If the resistance and/or hardness of the factory coating is not adapted to the anticipated geotechnical conditions, damages may occur even with a properly prepared borehole (abrasions, cuts, peel-offs, indentations, etc.).
- The compatibility of the field joint coating system with the factory coating and the anticipated loads needs to be assessed. The choice of factory coating can limit or determine the selection of the field joint coating system and prevent the use of the most suitable field joint coating system for the existing conditions.

Selection of field joint coating

- Incompatibility with the existing geological conditions can lead to damages caused by abrasion, slitting, peeling, indentations, etc.
- Incompatibility with the factory coating can lead to adhesion problems and thus to peel-offs and infiltration of water/drilling fluid/moisture.

Pipe diameter

Large steel pipes generally create higher upward or downward forces and thus higher loads on the coating, which can result in damages when combined with other influencing factors.

Wall thickness

The greater the wall thickness, the stiffer the pipe. This leads to greater forces between the pipe and the pipe coating as well as the borehole wall.

Quality of factory coating

Pipe storage

Improper storage, for example on sharp-edged supports, can create high point loads, which can lead to dents, grooves, notches or other damage.

Transport of coated pipes

Inadequate support or securing during transport can cause various types of damage.

Loading/unloading of pipes

The use of unsuitable lifting equipment can lead to various types of damage.

Quality of field joint coatings

Special care must be taken with the storage conditions of the base materials

- Materials may become brittle due to adverse weather conditions, resulting in premature failure of the coating.
- Multi-component coating systems may lose their chemical reactivity, leading to premature failure of the coating.

Surface preparation

Moisture, contamination, and inadequate preparation (such as roughening) can result in insufficient adhesion between the factory coating and the field joint coating.

Application

Non-compliance with the manufacturer‘s application instructions can limit the load-bearing capacity of the coating system.

Weather conditions

- Moisture from precipitation on the surfaces can result in insufficient adhesion between the factory coating and the field joint coating.
- Moisture due to condensation and inadequate preheating of the pipe surface can also result in insufficient adhesion.

Suitability of coating personnel

Untrained, inexperienced, or insufficiently aware personnel can significantly impair the quality and load-bearing capacity of the field joint coating due to processing deficiencies (see above).

Pipe construction

Design of overhead bends

Improper planning of overhead bends can result in excessive bending forces or point loads.

Execution of the overhead bend

Lack of care during lifting operations, insufficient number of roller supports, supports or lifting devices can result in high forces and stresses, and thus damage to the coating.

Placement of the pipeline on roller supports

Lack of care, dirty or damaged rollers, and roller supports that are the wrong size or improperly adjusted relative to the pipe diameter can cause high point loads.

Drilling execution

Drilling length

The longer the borehole, the higher the duration of the load on the casing during insertion and the greater the likelihood of damage.

Borehole size

The larger the borehole, the lower the stability due to arching effects, and the greater the likelihood of borehole collapse, falling rocks/debris, etc., which can increase the load on the casing at specific points and lead to damage.

Pipe weight/ballasting

The magnitude of the upthrust or downthrust force determines the mechanical load on the casing at the contact surfaces with the borehole wall. Inadequate ballasting can result in increased forces and hence damage.

Borehole radii

The smaller the curvature radii of the borehole, the greater the forces that occur radially between the curved pipe and borehole wall, which can lead to damage.

Upper bend radii

Small radii can cause overstretching/compression of the casing material, resulting in pre-damage or weakening and thus reducing the load-bearing capacity during insertion into the borehole.

Maintenance of drilling fluid circulation/pressure

- A lack of drilling fluid circulation increases frictional forces during pipe insertion and increases the risk of damage to the casing.
- A drop in drilling fluid pressure in the borehole can cause borehole collapses or falling of soil/rocks, etc., thus increasing the risk of damage

Borehole cleaning

Unremoved cuttings can increase friction.

Obstacles in the borehole

Any obstacle in the borehole, such as:

- Falling rocks/blocks, etc.
- Lost drilling tools/drilling tool parts
- Artificial obstacles that protrude into the borehole (e.g., foundations, contaminated sites, etc.)

can lead to increased load or directly to damage of the casing.

Operating conditions

Waiver of CCP (cathodic corrosion protection)

Since damages cannot be completely excluded, waiving a cathodic corrosion protection system increases the probability of inadequate or restricted usability and a shortened service life of the pipeline.

The above-mentioned aspects are listed in the first matrix and assigned a factor for the risk potential. The higher the factor, the greater the probability of damage to the coating in the event of a risk occurrence. In addition, each influencing factor is assigned a factor for the influenceability by the respective project participant (client, planner, pipeline builder, HDD contractor) based on generally common project conditions. The aim of this presentation is to sensitize and show responsibilities and thus the need for action. Who has decisive influence on the final coating quality after pipeline installation at which point. A second matrix using the same evaluation of the influencing factors can be used as a template for a project-specific evaluation.

Pipe casing and coating in HDD I March 2024

Attachment 2: Risk-Influencibility-Matrix for Quality and Efficiency of steel pipe coatings

1		2	3	4	5	6
Risk Potentials		**Risk factor (minor 1 - controllable 2 - critical 3 - very critical 4)**	**Influence HDD-contractor (minor 1 - middle 2 - high 3)**	**Influence pipeline contractor (minor 1 - middle 2 - high 3)**	**Influence engineer (minor 1 - middle 2 - high 3)**	**Influence client (minor 1 - middle 2 - high 3)**
Geology						
	Abrasiveness	3	1	1	2	2
	Weathering degree / fragmentation / fissuring	4	1	1	2	2
	Big stones / blocks	3	1	1	2	2
	Sharpness of the fracture planes / breaklines	4	1	1	2	2
	Voids	3	1	1	2	2
	Gravels	3	1	1	2	2
Material selection						
	Selection of factory coating	3	1	1	3	3
	Selection of field joint coating system	3	2	3	2	2
	Selection of steel pipe diameter	1	1	1	3	3
	Selection of steel pipe wall thick-ness	1	1	1	3	2
Quality of factory coatings						
	Site storeage of coated pipes	2	1	3	2	2
	Onsite transport of coated pipes	2	1	3	2	2
	Onsite loading/offloading of coated pipes	2	1	3	2	2
Quality of field joint coatings						
	Storeage of the raw coating materials	3	1	3	1	1
	Surface preparation	4	1	3	1	1
	Application	4	1	3	1	1
	Weather conditions	3	1	2	1	1
	Skills/qualification/aptitude of coating personell	4	1	3	1	1
Pipework						
	Design of the catenary	3	3	1	2	1
	Execution of the catenary	3	2	3	1	1
	Placement of pipestring on rollers	3	2	3	1	1

Pipe casing and coating in HDD I March 2024

Attachment 2: Risk-Influencibility-Matrix for Quality and Efficiency of steel pipe coatings

1		2	3	4	5	6
Risk Potentials		**Risk factor (minor 1 - controllable 2 - critical 3 - very critical 4)**	**Influence HDD-contractor (minor 1 - middle 2 - high 3)**	**Influence pipeline contractor (minor 1 - middle 2 - high 3)**	**Influence engineer (minor 1 - middle 2 - high 3)**	**Influence client (minor 1 - middle 2 - high 3)**
HDD execution						
	Length of the drilling	2	2	2	3	3
	Borehole diameter	1	3	3	2	2
	Pipe weight / buoyancy control	2	3	3	1	1
	Borehole radii	3	3	3	3	1
	Overbend radii	2	3	3	1	1
	Bad/lost mud circulation / -pressure	3	2	2	1	1
	Poor borehole cleaning	4	3	3	1	1
	Unknown obstacles in the trajectory	4	1	1	1	2
Operating conditions						
	Non provision for a cathodic protection system	3	1	1	2	3

Attachment 3: Risk Assessment Matrix

1		2	3	4	5	6	7	8
Risk Potentials		Risk potential	Before mitigation		Mitigation measures to reduce risk factor	After mitigation		Responsible parties (descending order)
			Probability	Existent risk [2 x 3]		Probability	Existent risk [2 x 6]	
Geology								
	Abrasiveness	3		0	Sufficient and informative soil report to get good knowledge of presence and location of critical formations, adjusting the drilling trajectory to minimize drilling in these formations	0%	0	CL/ENG
	Weathering degree/fragmentation/ fissuring	4		0		0%	0	
	Big stones / blocks	3		0		0%	0	CL/ENG
	Sharpness of the fracture planes / breaklines	4		0		0%	0	CL/ENG
	Voids	3		0		0%	0	CL/ENG
	Gravels	3		0		0%	0	CL/ENG
Material selection								
	Selection of factory coating	3		0	Careful study of the geotechnical report to decide on the materials Aligning the planned diameter with the operational condition	0%	0	CL/ENG - HDD
	Selection of field joint coating system	3		0		0%	0	CL/ENG - PC - HDD
	Selection of steel pipe diameter	1		0	Check whether the flow rate can be achieved with several pipes with a small diameter instead of one large pipe.	0%	0	CL/ENG
	Selection of steel pipe wall thickness	1		0	Check if wall thickness could be reduced by using higher steel grade	0%	0	ENG/CL
Quality of factory coatings								
	Storage of coated pipes	2		0	Check qualification of the manufacturer, specify and check storage conditions	0%	0	CL
	Transport of coated pipes	2		0	Selection of qualified carrier, specify and check transport conditions	0%	0	CL
	Loading of coated pipes	2		0	Use applicable loading devices, give instructions to the loading personnel	0%	0	CL

Attachment 3: Risk Assessment Matrix

1		2	3	4	5	6	7	8
Risk Potentials		**Risk potential**	**Before mitigation**			**After mitigation**		**Responsible parties (descending order)**
			Probability	**Existent risk [2 x 3]**	**Mitigation measures to reduce risk factor**	**Probability**	**Existent risk [2 x 6]**	
Quality of field joint coatings								
	Storage of the raw coating materials	3		0	Observe and follow manufacturer instructions	0%	0	PC
	Surface preparation	4		0		0%	0	PC
	Application	4		0		0%	0	PC
	Weather conditions	3		0	Provide for appropriate housings, tents and heaters	0%	0	PC
	Skills/qualification/aptitude of coating personell	4		0	Check qualification certificates of personnel, give precise work instructions and check compliance	0%	0	PC
Pipework								
	Oberbogendesign	3		0	Design the catenary in compliance with the DCA guidelines	0%	0	HDD - ENG
	Ausführung des Oberbogens	3		0	Use the applicable size and number of lifting devices and supports, give precise work instructions to the personnel	0%	0	PC - HDD
	Auflegen des Rohrstrangs auf Rollenböcke	3		0	Check condition, size, number and adjustment of the rollers, use appropriate equipment for lifting the pipestring and positioning of the rollers	0%	0	PC - HDD
HDD execution								
	Length of the drilling	2		0	Check minimum required length; if critical check alternative routes	0%	0	CL/ENG - HDD
	Borehole diameter	1		0	Decide for the borehole diameter as small as possible but as large as required, under consideration of the ground conditions	0%	0	HDD - ENG/CL

Attachment 3: Risk Assessment Matrix

1		2	3	4	5	6	7	8
Risk Potentials		**Risk potential**	**Before mitigation**		**Mitigation measures to reduce risk factor**	**After mitigation**		**Responsible parties (descending order)**
			Probability	**Existent risk [2 x 3]**		**Probability**	**Existent risk [2 x 6]**	
	Pipe weight / buoyancy control	2		0	Calculate bouyancy and evaluate applicability of pipe ballasting		0	HDD
	Borehole radii	3		0	Design the drilling profile with the largest possible radii, under consideration of the minimum allowable radius and with provision for drilling tolerances; if required adjust trajectory; observe accuracy of pilot drilling and surveying		0	HDD/ENG
	Overbend radii	2		0	Follow design and requirements of the planned overbend		0	HDD - PC - ENG
	Bad/lost mud circulation /-pressure	3		0	Observe the mud return flow and adjust drilling parameters and/or mud properties		0	HDD
	Poor borehole cleaning	4		0	Check theoretical and actual cutting volume; provide for a cleaning run, if required		0	HDD
	Obstructions in the trajectory	4		0	Observe drilling parameters, use appropriate drilling tools, gather all information about any existing obstructions in the ground		0	HDD - CL/ENG
Operating conditions								
	Non provision for a cathodic protection system	3		0	Check wether all residual risks evolving from the drilling and its local conditions justify, respectively tolerate to not provide for a cathodic protection system		0	CL - ENG

Risk assessment		Risk potential			
		4 (very critical)	3 (critical)	2 (controllable)	1 (minor)
Probability	100 % (substantial)	4,00	3,00	2,00	1,00
	75 % (high)	3,00	2,25	1,50	0,75
	50 % (medium)	2,00	1,50	1,00	0,50
	25 % (low)	1,00	0,75	0,50	0,25
	0 % (inexistent)	0,00	0,00	0,00	0,00

Abrevation

HDD	HDD Contractor
PB	Pipeline Contractor
EKU	Client Engineer
KU	Client

Verband Güteschutz Horizontalbohrungen e.V.
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