HDD applications in pipeline projects in Europe

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Essential Horizontal Directional Drilling (=HDD) in pipeline projects

Rigs for horizontal directional drillings are nowadays part of pipeline construction projects and are among excavators, hoisting cranes and other common auxiliary tools. This ever increasing trenchless technology contributes a technical and economic edge as well as providing environmental and productivity advantages. The main applications for HDD pipeline projects are under-river crossings, traffic way crossings (canals, railways, highways, roads, runways, etc), flood protection dams, crossings below foundations of buildings or infrastructure objects, shortenings through topographic obstacles like rock ridges, orthogonal situated hills and rims, non-crossable terrains and e.g. under-crossings of nature reserves, parks or even hole city areas or mountain zones. HDD rigs of different size and type are used for pipeline installation projects of differing lengths, depths, curves, geology as well as technical and environmental conditions.

Range of HDD machines

There is a wide spread range of HDD machines for the trenchless market, ranging from a 1.5 tons pit machine to a 550 tons mega rig. The principle of the directional drilling process remains the same however the pulling force of this HDD machines differs by a factor 1:300. HDD machines in the 1.5 t to 4 t-class are only used for house connections and street crossings.

Horizontal directional drilling units most frequently required are those in the performance range of 7 t to 20 t thrust and pulling power as these units are very well dimensioned for standard pipe installations in residential areas and city centres. Smaller units (7–10 t-class) are often used for longer house service connections or in very restricted environments, while the larger units are employed for installing drainage pipes, smaller dimensioned under-river crossings, environmental or geotechnical bores as well as small pipeline and sewer pipe installations. As a rule, the specialist company will always select the equipment best suited for the project after consulting with the customer.

For installing pipelines over longer distances (middle to high pressure pipelines) HDD machines from the 35 t-class up to the biggest units existing in the HDD market are required. Nearly all obstacles along pipeline traces like rivers, lakes, mountain ridges, traffic lines such as railways with highways and roads can be overcome with the HDD technique, thus open river crossings or open crossings of traffic lines get out of use for environmental and economic reasons. All long-distance pipeline projects in Europe and Northern Asia have an essential need for HDD crossing jobs under natural and artificial obstacles. An overview of such HDD applications in pipeline projects is presented in this paper.

HDD for under-river crossings

Underwater crossings (of rivers, canals, lakes) which would otherwise require a special construction effort, can be executed using the trenchless HDD method in the same way sections can be installed in the normal route of roads. Underwater crossings are particularly advantageous because no special ground water retention is required that necessitates other structural preparation measures; only the bore path is steered in a curve under the obstacle. Overground and combined underwater crossings are HDD standard applications. A great number of them are performed every day.

In pipeline projects the jobs get divided in sections of open trenching and sections of under water crossings and crossings traffic ways and other obstacles. Nowadays, normally all underwater crossings are planned and projected for HDD machines. The selection of the machine’s power class depends
on the depths and the lengths of existing water obstacles, the geological underground in relation to the diameter and the weight of the pipe section. Often various HDD machines are working at different spots and with different crossing tasks for the same pipeline project. The longest underwater crossings were done in 2004 and 2005 when crossing the river Wolga in the river Elbe at a length of 2.2 and 2.6 km. River crossings in Europe are primarily done in the summer or winter time because in the springs time rivers often are flooding. In Siberia river crossings are primarily executed in winter time when the permafrost ground is frozen and the rivers themselves are covered with a load resistant ice crust which made it easy to transporting equipment like rods and tools from the one river side to the other. This offers a logistic advantage. On the other hand the drilling rig must be covered with a thermo tent so that drilling operations even below minus 30 °C can be performed.

The preferred pipe material is steel and protected steel (concrete cover, polyethylene cover), mainly for oil and natural gas pipelines. Cast iron pipes and PE pipes are often used for sewers whereas PE and steel pipes are preferred for water transport pipelines. Due to the weight of the pipes for long under water crossings the machine choice tens towards more powerful HDD units. In recent years a couple of river crossings were done through rock because the mud motor technology enables to penetrate all kinds of geological conditions. A major challenge for HDD under-river crossings is the permanent change between hard and soft rock layers below the river bed which are to be found in all rivers coming from high mountain ranges. These rivers have rocks and boulders, rough gravel and pebbles between fine grain material in their ground and the drilling under these conditions needs experience and feeling for the ground conditions. Anyway, the number of under-river crossings in this challenging geology is increasing, more and more experienced HDD companies successfully carry out impressive crossing jobs in these ground conditions.

Thanks to HDD, the majority of all crossings, and under-river crossings is carried out using this trenchless method with a trend towards trenchless installations growing to over 90 % particularly over the past few years. Many companies have meanwhile specialised in such applications and perform them exclusively. Thanks to the rock drilling technique using low-flow mud motors there are no longer any soil conditions that cannot be coped with by drilling. The only thing that needs to be done is to select the optimum HDD system size, the optimum drilling fluid for the type of soil and the best suitable bore tools and steering equipments.

Rivers and lakes with depths of 200 m or even 300 m can be crossed using 20 t-bore rigs. Using maxi and mega bore rigs, rivers and lakes more than 2,500 m wide have already been bored. The dimension of installed pipes has already reached walk-through diameters. Mega rigs have especially been built for large-scale crossings and under-river crossings, rock drillings and large infrastructure projects. The demand for very powerful mega rigs is increasing and rigs above the magic 500 t-class will be constructed mainly for large under-river or under lake crossings for pipeline installation projects.

Rhine river crossing in Alpine Boulders in Basel, Switzerland

The river Rhine flows through a relatively narrow and deep bed in the municipal area of Basel, with buildings and traffic ways on both sides and in immediate vicinity. In every sense of the word, Basel is “closely” connected to the Rhine, which changes directions from the “Alps Rhine” to flow as the “Upper Rhine” to the north. This gate position results in a pile up of gravel, blocks and boulder material 17 m below the river floor. Many boulders have a half meter and even more in diameter and they consist of naturally transported material from the central and the northern Alps. Underneath lie solid clay and sandy marl layers in close succession with gravel and boulder layers which have completely opposite characteristics as far as drilling techniques are concerned.

A large chemical manufacturer commissioned a Swiss building contractor to install a network of empty PE-pipes underneath the river Rhine to host fibre optic communication cables and chemical product pipes. A section of the required installation was the undercrossing of the river at a depth of 24 m.

In awareness of these difficult ground conditions, the contractor choose a 50 t-drilling unit from Prime-Drilling, particularly because the length of the undercrossing was to be 400 m. The 50 t-rig was an excellent choice for this job, because of its good drilling abilities, even taking the difficult underground and the confined space into account (Figure 1). Beside the PD 50/33, a recycling system with a flow rate of 1,000 litres of drilling fluid per minute was used. The machine was equipped with a mud motor bearing a 200 mm drill head with TCI-bits for the gravel and stone layers and mill tool bits for the pilot bore through clay stone and sandy marl below at a depth of 17 m. The roller bit head had to be driven out and exchanged four times during the pilot bore because of the constantly alternating geological conditions. Several days of work were required for the pilot bore. The first upsizing bore was carried...
out with a 350 mm hole opener with TCI-bits, while a hole opener with a diameter of 450 mm was used for the second reaming operation. A third check reaming followed with the 450 mm hole opener and a fly cutter attached to the rear. The 355 mm host pipe was pulled into the 450 mm bore hole as a final working step.

The whole project in this difficult underground and limited space on the factory site was finished within six weeks including a river crossing at 24 m depth and the complete cable installation.

Gas pipeline project near Torino, Piemonte, Italy

A very impressive job site was completed in 2006 in the Alpine foreland northeast of Torino. Near the city of Chivasso, the Orco river had to be under crossed over a length of 1,249 m for a 660 mm steel pipeline for natural gas. The Orco river, directly coming from the Gran Paradiso Mountains in the Graie Alps (reaching 4,061 m altitude) is a “wild river” with a high transporting energy and with sudden water level alterations with a frequent danger of flooding (Figure 2). Rivers from the high mountains have rough gravel below their river bed, mainly a wild mixture from boulders to sand.

Several days of work were required for reaming steps and a special reamer was built to carry out hole expansion with a 900 mm hole in very difficult underground. In this project the fly cutter was not used to cleaner hole for presence of big gravel and boulders (size: diameter from 60 mm to 120 mm up to 8.0 m depth). In pipe site big trench was made and a lot of gravel was removed to eliminate critic soil and favour pullback. In this site during drilling activities an other very big trouble was phreatic surface but pumps system was implemented to dry the trench.

The HDD drilling job was well done by the experienced pipeline construction company Ghizzoni S.p.A. with their 460 t-Prime Drilling rig, and even under winter conditions (Figure 3).

Gas pipeline project near Vibo Valenza (Valentia), Calabria, Italy

A huge pipeline project in the very south of Italy with a 48” natural gas pipeline was realised in 2005 by the very experienced company Ghizzoni S.p.A. with their 460 t-Prime Drilling rig. The Mesima river, coming from the Appennino Calabrese, was crossed three times in different pipeline sections. Step by step bore hole reamings up to 1,600 mm were created at this job site, which are shown in Figure 4, Figure 5 and Figure 6.

The first expansion (pilot bore) was carried out with a 250 mm hole opener with milled tooth bit, while a barrel reamer with a diameter of 600 mm was used for the second reaming operation. Other check reaming followed with the following barrel reamer: 900 mm 1,200 mm 1,400 mm.

The last check reaming followed with the 1,600 mm barrel reamer and a fly cutter attached at the back.

The 1,200 mm host pipe was pulled into the 1,600 mm bore hole (30,9 % Over Cut) as a final working step.

A lot of side-booms and rollers were used during pullback to make stable the pipe and an over bend was realized with the 1,200 m radius.

The work was completed in 2005 under southern temperatures to the complete satisfaction of the customer.

Jobsite details:
Realisation year: 2005
Customer: Snam Rete Gas S.p.A.
Gas-Line: Palmi – Martirano
OD pipe: 48” (1,200 mm)
Wall thickness: 18.9 mm
Material: EN L455 MB – API 5L X65
Pressure: 75 bar
Borehole reaming: 62” (1,600 mm)
Rig: Prime Drilling 460 t
Mesima River crossings:
   a) from 8th to 9th pipeline section (Rosarno-Serrata) – length 550.0 m – min. radius 1,490 m about
   b) from 10th to 11th pipeline section (Rosarno-Serrata) – length 530.0 m – min. radius 1,500 m about

Jobsite details:
Year of project: 2006
Customer: Snam Rete Gas S.p.A.
Gas pipeline project: Bellinzago – Torino
Material: EN L415 MB – API 5L X60
Pipe OD: 26” (660 mm)
Wall thickness: 15.9 mm
Length: 1,249.1 m
Minimum bending radius: 1,063.7 m
Entry point angle: 9°
Exit point angle: 9°
Pressure: 60 bar
Upsizing bore: 36” (900 mm)
Site: Chivasso (TO)
Crossing: Orco River
Soil type: Sand & gravel
Rig: Prime Drilling 460 t

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12th pipeline section (Mesima River) – length 480.0 m – min. radius 1,600 m about

Soil type: Silt - Sand – Gravel

Undercrossing the Alp Lake in Allgeau Alps, SW Bavaria, Germany

The Alp Lake is located 725 m above sea level in the west of Immenstadt in the Allgeau Alps between Lake Constance and Tirol (Tyrol). The mountains north of the lake reach an altitude of 1,100 m, south of the lake more than 1,800 m. The Alpsee itself has an east-west length of about 4 km and a north-south reach of maximal 1,100 m. The maximum depth of the lake is 24 m. The geology beside and below the Alpsee is determined by layered sequences (Tertiary), on the lake ground moraine material is sedimented.

The city of Immenstadt had the duty to build a ring sewer system around the lake, with 560 m of gravity pipes, 9,100 m of pressure pipes, 35 pumping stations and the necessary equipment. A 2,300 m section of the 9,100 m pressure pipeline has to be installed below the lake ground, with the most pretentious task being a north-south lake crossing of 600 m length in the western and smaller part of the lake. The depth of the Alpsee is 16 m there, the pressure pipe had to be positioned at minimum 3 m below the lake floor.

The city of Immenstadt assigned the experienced company Max Wild from Illerbachen for this lake crossing for. Max Wild used a Grundodrill 20 S HDD unit from Tracto-Technik and even a small boat for navigating the drill head from the water level. The pilot bore was done with a soft rock drill head because the ground moraine and the following changing layers allowed for this method. Boulders were overcome and a path was drilled successfully without interruption in one day and the following night. The first reaming step together and pulling in the pipe from the other side of the Alp Lake was also done in one day and one night. The effective lake crossing distance was 650 m, the longest lake crossing in the Alps, carried out with a 20 t-drilling rig in an extremely short drilling time leaving a very content and impressed customer.

HDD for crossing traffic ways

Especially when undercrossing traffic ways like railways, highways, roads, streets, runways etc. pipelines have to be embedded safely and with stability in the existing underground infrastructure. Using the sophisticated HDD method it is possible to drill small to large diameter boreholes and keep these boreholes and the surrounding underground stable during the pilot boring or during reaming for the embedded pipeline later. With the HDD pilot process, there is normally no unsteered or non-surveyable moment, so the drilling head is under permanent navigation and positioning control. This is very important with regards to underground infrastructure safety and it is an important advantage in comparison to non steerable or uncontrollable methods. HDD crossings do not interfere with the underground, structure and the drilling fluid is a smooth transport medium safely embedding the cuttings of soft or hard ground. Using wireline systems for detection avoids accidents has operators don’t have to walk over busy streets. HDD has the enormous advantage that neither manhole have to be built nor groundwater control is required during the installation.

Bore under a runway at Airport Friedrichshafen, Germany

The airport Friedrichshafen-Löwental near Lake Constance was founded 1913 and is an airport, for airships (zeppelins) and regular aeroplanes. When a second hangar for the airships was built, a water pipeline connection between the aeroplane maintenance building of and the new airship hangar became necessary. The complete plane runway had to be under crossed over a distance of 450 m (Figure 7). A soil investigation took place primarily along the bore path. The geological survey indicated that the airport area is situated in an old, completely silted sea with flat valley sediments. It was decided to used the Grundodrill 20 S HDD rig, a 20 t-unit. In the runway area, drainage and sewage pipes of various diameters laying at different depths parallel and orthogonal to the runway had to be considered leaving a crossing depth of 5 m. Due to aviation safety restrictions walking over the runway to detect the pilot bore was only permitted a few hours during the night.

The experienced bore crew of company Max Wild from Berkheim realised this in a short time. The upsizing bore was done twice, the last step with a 480 mm reamer. The bore channel was completed to perfection, so a HDPE protection pipe with 355 mm diameter and a total weight of 11.7 t was pulled in with the Grundodrill 20 S. The pipe pulling-in process took 16 hours. Then the 225 mm water pipe type SDR 11 PE 100 was pulled in with the bore rig taking roughly 15 hours, because every 2 m plastic skids had to be assembled, which disturbed the continuous pulling-in process. Just 14 days after completion of the bore the drinking water pipeline was taken into operation. The jobsite was cleared after 5 days as required, thanks to the careful planning and professional completion.
With HDD through the mountains

The use of trenchless technologies for both new pipe installations and the pipe renewal in hillsides provides beneficial advantages. Expenses that are typical in classical civil engineering, such as special walking excavators, safety measures supporting the slope, special sheeting, safeguarding of the excavated soil, bracings in the trench, special and difficult compaction work when backfilling the excavated soil on the slope and complex landscape conservation work can be completely avoided. With the same equipment which is used for horizontal directional drilling to install pipelines or to under cross rivers, roads and railway embankments, house connections in hillsides can be "drilled through". Costs are about the same as for bores in flat terrain. The additional depth in difficult soil does not constitute any additional expenditure. By installing new pipes using the trenchless method, garden vegetation that has been carefully cultivated and cared for is preserved without damaging the soil structures of the roots. In critical hillsides that often require a renewal of pipes with flexible plastic pipelines due to the amount of swelling clay minerals in the soil, trenchless construction methods offer additional advantages that can have moderating and stabilising effects on the slopes.

Shortening through the Swiss Jura mountains near Reigoldswil

Reigoldswil is located in the canton of Basel-Land and embedded in folded Jura mountains which reach the altitude of 900 to 1,200 m. A natural gas pipeline, existing since 1967, had to be replaced and deviated near the village area of Rapperswil. The new section of the steel pipeline to be replaced was 900 m in length, now situated farther away from the next buildings. The network owner, the Gasverband Mittelland AG, decided to cross within a mountain ridge over a length of 460 m. The mountain ridge "Bergli" consists of a typical Upper Jurassic sequence with hard limestone and weak marls in frequently changing layers.

For realising the project in summer 2005, first a small street up the mountain side had to be built for transporting the 100 t-Prime Drilling HDD unit to its starting place (Figure 8). The experienced drilling company Bohlen & Doyen from Germany, owner of the 100 t-Prime Drilling unit, established the pilot bore with a mud motor equipped with a 250 mm roller bit. Control of the bore was realised using an artificial magnet field in the drilling area and a detection system behind the bore head a wireline inside the drill rods connected to the control board of the machine.

The drilling process in the Jurassic layers required constant adaptation of the drilling fluid mixture due to the strata dominance in the bore hole. The complete drilling fluid was recycled on site. The second working step was to upsize the borehole with a 500 mm hole opener. The third step was to pull in the welded steel pipe Ø273 mm into the borehole, which was filled with a enriched drilling fluid.

The job site was finished exactly in the given time, the customer was very content and used reports on this jobsite for promotional purposes in Switzerland.

Possibilities for geotechnical investigations for tunnel projects

Using controlled HDD, geological investigations in the future can be made for planning prospective tunnel routes (one example is the new Mont Blanc railway tunnel). In doing so, liquid probing and solid rock probing using certain instruments can be achieved. In addition, geotechnical instruments can be installed. HDD boreholes can also be used for geophysical investigations. With the help of several parallel but vertically and laterally raised boreholes, investigations in the borehole can be performed by means of geophysical instrumentation which provide geophysical 3D surveys of entire sections of rock, i.e. detailed three-dimensional investigation.

These investigations are of particular importance if tunnel sections run through swelling rock (e.g. anhydrite, swelling clays), through tectonically weak zones or mellow rock horizons, through banking layers or anomalies.

Tunnel improvement

Many older tunnels were directly cut out of rock. They have no inner shell and sometimes mains and services supply lines are under capacity. As a result of new fire protection regulations in tunnelling, additional fire mains, for instance, can be installed with HDD rock drilling and delivery pipes for fire fighting water can be laid on the tunnel floor. Bores for additional ventilation and air extraction as well as pilot bores for rescue tunnels and crossovers can be realised with HDD: Moreover, consolidation in friable old tunnel sections, for example, is possible with concrete injections using HDD.

Advantages of HDD applications

The most striking advantage is the preservation of the traffic way or ground surface as static/dynamic supporting structure. The natural structure of the soil above the pipe-installed underground is completely pre-
served. An even ground drilled in duct form based on optimum static calculation and preserved in its cohesive soil structure ensures even static loads above and around the pipe so that point loads are completely avoided with firm pipe embedding already discussed. The pipe is installed in a round borehole. Due to the cylindrical geometry of the borehole or the micro tunnel, respective tensions in the soil will be diverted almost ideally around the cylinder in arch form, as the untouched superstructure has a very strong supporting effect. Complete filling of the annulus between pipe and cylindrical hollow body ensures an even better diversion of the mechanical line of tension in the soil. Compressive strain and tensile stress are relatively balanced. If pipes are covered in accordance to regulations, the load on the pipe is definitely lower than with open construction.

As the removal of excavated soil and the transport of the above mentioned resources are kept to a minimum, residents will not be annoyed as a result of high traffic and noise and there will be no obstructions of traffic and entries. A construction site that is almost independent of weather conditions also allows high working speeds so that only a fraction of the time (only a quarter in some instances) will be required for trenchless pipe installation work as compared to open trenching.

In trenchless construction, installation depths have no influence on the cost since the only cost determining factors are boring and backreaming. The installation of pipes to be laid at great depths can be carried out especially cost effectively using horizontal directional drilling.

With horizontal directional drilling using mega rigs, bores under busy traffic routes (roads, railways, waterways, runways for take-off and landing) do not cause any short-term traffic restrictions; with standard drilling technique there will only be very short-term and almost selective obstructions during detection of the pilot bore. As this is an ongoing process, traffic restrictions are normally limited to a few minutes only.

In hillside locations where any conventional open trench installation requires special effort and expense, horizontal drilling works at nearly the same bore speed as in even terrain.

Under valuable flora and fauna, in parks, under rows of trees or habitats, horizontal directional drilling does not impair the natural cover in any way as roots can always be crossed without any problem and without additional cost. The same applies to plants on riverbanks when crossing under-rivers.

Horizontal directional drilling with mega rigs, moreover, allows major transmission instal-

![Image]

**Literature**


**Internet links**

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[6] Manufacturer’s information provided by Prime-Drilling GmbH, Wenden-Gerlingen

**Authors:**

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Fig. 1: The Prime Drilling 50 t rig inside a factory plant in working position

Fig. 2: The Orco River close to the under-river crossing site
Fig. 3: Typical winter conditions in the Alpine foreland. The 460 t-rig is working under all conditions

Fig. 4: The 460 t-PD-rig working for a 48” pipeline project in Calabria, Southern Italy

Fig. 5: Reamers for the last two upsizing steps

Fig. 6: Pull-in process of the 48” pipe
Fig. 7: Overview to the runway under-crossing for a water pipeline at Friedrichshafen.

Fig. 8: The 100 t-Prime Drilling-unit of Bohlen & Doyen Company in working position in the Swiss Jura of Basel-Land.