Trenchless installation methods of Sea Outfalls.

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Abstract
Trenchless mechanized tunnelling technology has less impact on the environment and existing infrastructure than methods applying open cut trenching. Pipelines that are laid underground are better protected against damage and therefore have a longer life expectancy than those laid aboveground. For the installation of sea outfalls and intakes, Horizontal Directional Drilling (HDD), Direct Pipe®, pipe jacking (Microtunnelling) and segment lining technology may be used, depending on site and ground conditions, pipe diameter and length of the pipe string to be installed. However, feasibility, technology and economic factors also play an important role.

Keywords
Tunnelled Outfalls, Intakes, Horizontal Directional Drilling (HDD), Tunnel Boring Machines (TBM), Microtunnelling, Pipe Jacking Easy Pipe, Direct Pipe, Trenchless Technology, Ocean, Submarine

INTRODUCTION

With the exception of Mexico City, Beijing and Moscow almost all metropolitan areas in the world are located next to coastal waters. In addition, more than half of the world's population lives within 60km from the coastline. Therefore, the construction of outfall tunnels is often an effective and sustainable solution to improve the quality of life in the coastal areas. With the help of sea outfalls, wastewater can be discharged far away from the coast to allow for its better diffusion, dispersion and dilution. In this context, the municipal wastewater may be fully treated or pre-treated.

Water intakes are also installed, for example, to supply water to desalination or power plants. If rocky geology or high cliffs are located close to the plant, a tunnel off the coast is an ideal solution to supply the water.

Conventional pipe installation of sea outfalls requires the pipe to be prepared on the construction site. Then the pipe is pulled over the seabed into the right position, sunk and anchored. In comparison, trenchless tunnelling technology has significantly less impact on the environment and existing infrastructure. And the pipeline is better protected against damage and therefore has a longer lifetime.

ADVANTAGES OF TRENCHLESS TUNNELLING TECHNOLOGY FOR SEA OUTFALLS

Often, sea outfalls or intakes can be installed with both trenchless and open cut trenching methods. The main benefits of trenchless tunnelling technology compared to open cut trenching are:

a) Minimum impact on the environment:
   - minimum damage of the seabed (tidal flat, coral reefs etc.)
   - no deterioration of sea water quality
   - fewer emissions

b) Minimum impact on existing infrastructure:
- realization in densely built-up urban areas possible
- no disturbance of tourism
- no limitation of shipping traffic.

c) Longer lifetime of the pipeline:
- less risk of subsidence, higher seismic safety
- better protection against storms, hurricanes and the corresponding impacts
- better protection against general environmental impacts, e.g. weather conditions such as low and high tide, currents and sediment transport
- protection of the pipeline, e.g. against damage by ships.

d) Minimum efforts to reinstate the site following pipe installation

e) Independent of weather conditions and waves during the construction phase

Influence from currents on pipelines laid on the seabed

Pipelines laid on the seabed are exposed to the direct influence of hydrodynamic forces resulting from currents. Typical turbulences caused by orbital movements of wave particles and near-coast currents may damage the pipes, in particular during a rough sea or storms. Hydrodynamic forces cause erosion, as well as the transport and accretion of sediments. In general, offshore buildings influence currents, which may cause heavy erosion or accretion near to these buildings. Pipelines which are laid on the seabed may alter the current velocity and thus cause turbulence. A two-phase flow of sand and water may occur under the pipeline. This leads to undercutting depending on the following parameters: the vertical profile of current velocity, turbulence, wave reflection and sedimentation.

If the pipeline is laid directly on the seabed, undercutting may cause a long, freely suspended span between two pipeline supports. If the pipeline has been laid on concrete supports, undercutting may cause the supports and the pipeline to sink. The bending radius of the pipeline between two supports may thus be exceeded and the pipeline may break.

PIPE JACKING / MICROTUNNELLING FOR SEA OUTFALLS

In this example, the Microtunnelling technology is used to install a sea outfall on a steep coast. The pipe string is made of reinforced concrete tubes, has an interior diameter of 2.0m and individual pipe lengths of 3.0m. The length of such an outfall or intake is between 500m and 1,200m. The Micromachine is a Herrenknecht AVND2000AB with a length of 9.30m and a weight of approx. 40t.

Picture 1: Sea Outfall jobsite installation

On the last 50 meters, the pipe segments must be firmly connected to withstand buoyant forces when flooding the tunnel. When installing the diffusers, the tail pipes of the tunnel must be weighted down with solid ballast, if needed, to avoid buoyancy. All barges required for offshore work must be adequately moored so that they can withstand the forces resulting from currents or during recovery.

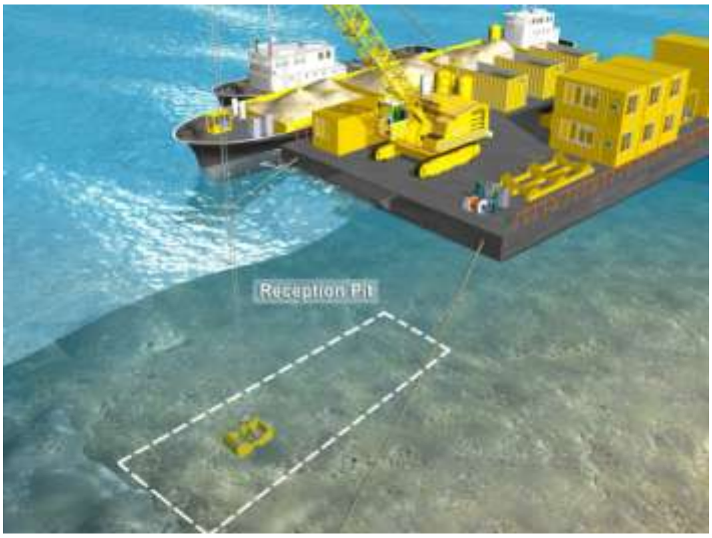
Installation of the pipe string

A launch shaft is built out on the land side of the pipeline. Due to project-specific conditions the dimensions and the design of the launch pit may vary, economic considerations being a key factor. A thrust wall is being constructed to create resistance to jack the pipe string ahead. The correct pipe jacking direction at the start of tunnelling is achieved by positioning guide rails in the launch shaft on which both machine and pipes can be aligned exactly.

High-performance hydraulic jacks are used to press the jacking pipes through the ground. At the same time, a steerable Micromachine excavates and removes the soil. The remote-controlled Herrenknecht Microtunnelling machine is operated from a control panel in a container which is located aboveground close to the launch shaft. This guarantees a high degree of safety, since no staff has to work in the tunnel during tunnelling. The Micromachine's position is monitored by a remote-controlled surveying system. During the construction phase the necessary tunnelling forces increase constantly due to the skin friction on the growing length of the pipeline already installed. Intermediate jacking stations and an automatic bentonite lubrication system are installed to reduce the tunnelling forces and to better distribute them. This results in a reduction of the forces of the hydraulic main jacking stations acting on the launch pit and the thrust wall. Tunnelling tolerances achieve values of less than 30mm. The seaside end of the pipeline is closed with a bulkhead equipped with a valve.

Excavation of the recovery zone

For the recovery of the Micromachine a pit or a depression must be excavated from the seabed which is big enough to allow the recovery. This can be done, for example, using an excavator or a suction pump.



Picture 2: Excavating the reception pit

Recovery using a floating crane

A floating crane is positioned at the place from where the Micromachine is to be recovered. There are lifting eyes on the upper side of the Micromachine. The Micromachine's lifting eyes are connected to the crane with the help of a spreader beam. Divers make all necessary connections. Then the floating crane lifts the Micromachine onto a boat or a pontoon and the machine is brought to land by a barge or a boat.

Picture 3: Recovery by crane

OUTFALL TUNNEL INSTALLED WITH SEGMENT LINING

A desalination plant was built south of Tugun in Australia, to counteract the shortage of drinking water caused by the subtropical climate. In November 2008, the project was successfully completed. The plant is now treating seawater and supplies up to 250 million liters of drinking water every day (as of Dec. 2009). Two tunnels run beneath the beach and its hotels as well as a highway and form an inlet pipe with a length of 2.2 kilometers and an outlet pipe with a length of 2 kilometers. For this project, two Herrenknecht AVN2800AHs started at a depth of 70 meters to tunnel through hard rock with strengths of up to 100 MPa (megapascals) and groundwater pressures of 5 to 7bar. Along the route, three curves with radii of 400 meters had to be driven precisely. The two Utility Tunnelling machines began their journey in June 2007. After less than eight months, they reached their targets in February and March 2008, respectively, despite the very difficult conditions.

HORIZONTAL DIRECT DRILLING (HDD)

Horizontal Directional Drilling (HDD) is used for the construction of water intakes, sea outfalls for wastewater disposal, and landfalls for oil, gas or telecommunication pipelines.

In line with the project conditions there are two optional construction methods and drilling directions: If drilling starts onshore, the HDD rig is installed at the coast. In this case, the drill rods connected to the product pipe float in the sea and are then pulled onshore using the rig.

Picture 4: Drilling starting onshore: The Herrenknecht HDD HK250T machine in Norway, rock drillings for a landfall tunnel – 20” gas pipeline with gradient

Alternatively, the drilling begins offshore and the rig is installed on a pontoon or a barge. In this case, the product pipe is prepared onshore, assembled, connected to the drill rod and then pulled onto the seabed by the rig. Offshore installations must be designed in such a way that they are able to withstand hydrodynamic forces and the forces during the construction phase. The pipe is protected against corrosion and wear and tear by a fiberglass-reinforced epoxy coating or by a polypropylene coating. When welding, a fiberglass-reinforced epoxy coating is easier to handle than polypropylene.

Installation and drilling of the pipeline from the seaside (offshore)

If the drilling is carried out from a modified jack-up platform (barge), the barge is directly positioned at the place where the drilling shall take place. The horizontal drilling rig is positioned on the barge relative to the entry point of the drillings into the seabed. The protection pipe is held in place by a steel construction which is anchored in the sea. The product pipe is prepared onshore and then positioned on supports of different heights to maintain the bending radius. The drilling rig and all other facilities required, such as the drill rod, storage container for slurry water and container are installed on the jack-up platform. The HDD rig has sufficient pulling force to realize the total length of the drilling with the planned pipe diameter. The jack-up platform must be designed in such a way that it is able to withstand these forces. If the jack-up platform is not able to withstand the pulling forces, it must be additionally anchored.

The drilling procedure starts with a pilot drilling with a small diameter. The direction of the pilot hole drilling is controlled in order to comply with the planned pipe string route with a tolerance of centimeters or meters in line with the site conditions. If the pilot drilling has reached a length of approx. 80m, a slurry pipe is jacked in rotary mode until it is in a position of approx. 30m behind the drill bit.
In order to enlarge the borehole, several reaming steps have to be carried out. A pull back pipe is attached behind the reamer. The reamer is then pulled towards the drill rig. As soon as the borehole has reached the size required for the product pipe, the reamer is connected with a swivel which is attached to the towhead of the product pipe. Now the HDD rig pulls the product pipe into the

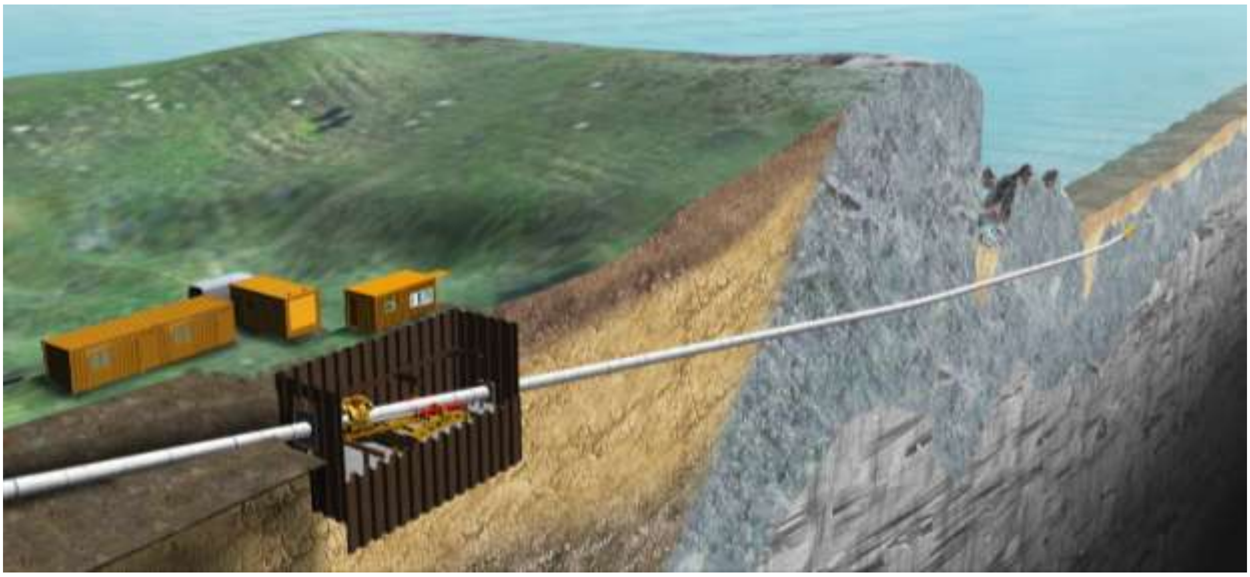
prepared hole from onshore. Part of the slurry water remains in the annular gap protecting the product pipe. As soon as the product pipe's towhead has reached the target position on the seabed, the sleeve pipe is pulled in such a way that the shackle which connects the swivel to the product pipe can be removed by a diver. The pullback pipe with the reamer is now pulled onto the jack-up platform. Following the installation of the pipe string, the construction of the water intake or water outlet structures starts.

Picture 6a Drilling from onshore

Picture 6b Drilling from offshore: Pipeline construction with a Herrenknecht HDD rig in Indonesia

THE DIRECT PIPE® METHOD ALLOWS DIRECT LAYING OF PRODUCT PIPES AND OTHER PIPELINES, FOR EXAMPLE, FOR OUTLET AND INTAKE STRUCTURES.

The Direct Pipe® method combines the advantages of the tried-and-tested Microtunnelling construction method with Horizontal Directional Drilling (HDD) and thus opens up new application opportunities. Flexibility regarding the geological conditions, time saving and cost reduction are the key criteria when selecting the most suitable technology. The Direct Pipe® method allows the drilling of a borehole and the trenchless installation of a prefabricated and tested pipe string at the same time in one single continuous work phase. As with pipe jacking, the soil is excavated by a Microtunnelling machine (Direct Pipe® machine). The cutting wheel can be adapted to each project in line with the geological conditions and helps to remove potential obstacles. The machine transports the excavated material aboveground via a flushing circuit and is navigable. The machine's position on the planned tunnel route is monitored using the highly modern technology of controlled pipe jacking. The forces necessary to jack the pipe string are exerted by an innovative thrust unit, the Herrenknecht Pipe Thruster, a development of Herrenknecht AG. The Pipe Thruster pushes the pipeline forward with four clamp segments which hold the pipe from outside. The pressure necessary for tunnelling is transferred to the cutterhead via the pipe string. This technology can also be used for the construction of sea outfalls or intakes.



Picture 7 View of a Direct Pipe® construction site

Overview of the advantages of Direct Pipe®:

Technical advantages
- Pipe strings are installed rapidly and in a single work phase.
- Permanent (constant) borehole support.
- A collapse of the borehole with surface cracking is not possible.
- The cutting wheel can be equipped in line with all geological conditions.
- Conveyor lines remove the excavated material safely from the borehole, subsidence in the borehole is not possible.
- Curved routes can be driven preciously to the centimeter, avoiding excessive bending stress on the pipe string and excessive laying forces.
- Operations in the target pit are only necessary to dismantle the cutterhead.

Economic advantages
- Low space requirements in the launch and target pits.
- A minimum of slurry is needed.
- Due to a very small overcut the borehole diameter can be reduced to a minimum, which results in a considerable reduction of excavated material.
- The drilling time can be reduced, no coupling times are needed and the pipe string can be installed in one single, continuous work phase.
- Taking into consideration the project requirements, no permanent protection pipes/casings are necessary.

APPLICATION AREAS FOR DIFFERENT INSTALLATION METHODS

It always depends on technical, time and economic factors which of the described installation methods will be applied. The following table compares the suitability of four methods for a variety of site conditions.

		Microtunnelling	Segmental lining	Direct Pipe®	HDD
Soil	cohesive	+	+	+	+
	sand	+	+	+	+
	gravel	+	+	+	-
	bolders	+	+	o	-
	mixed	+	+	+	o
	rock	+	+	o	+
Pipe material	PEHD	-	-	-	+
	steel	o	o	+	+
	GRP	o	-	-	+
	concrete	+	+	-	-
Pipe diameter	≤ DN1000	o	-	o	+
	≥DN1200	+	-	+	o
	≥DN2000	+	+	-	-
	> DN3500	-	+	-	-
Laying length	≤ 100m	+	-	+	+
	100 – 500m	+	o	+	+
	500 – 1,200m	+	+	o	+
	>1200m	o	+	-	+

Table 1: Suitability of trenchless installation method for different site conditions

Legend:
(+ : particularly suitable, o: conditionally suitable, -: not suitable)
DN: nominal diameter
GRP glass fiber reinforced
PEHD Polyethylene High Density

CONCLUSIONS

The advantages of sea outfall tunnels are: There are no impairments, neither for the coast nor for the people living there. The method is environmentally friendly and the tunnelling work does not depend on climatic conditions, such as waves, storms etc. In addition, the installation of the pipe string can be carried out using tunnelling technology on an onshore site. There is no hazardous handling of the pipe string during installation or floating and in connection with expensive offshore equipment and diving teams.

Herrenknecht Microtunnelling technology allows for the construction of long sea outfalls which can be jacked deeply beneath the seabed – under almost all geological and topographic conditions. Herrenknecht machines are very suitable for rocky /mixed grounds, also under water. Horizontal Directional Drilling and outfall tunnels which are built with the segment lining method, the Direct Pipe® method or with pipe jacking technology (Microtunnelling) do not depend on the costal conditions, i.e. outfalls can be driven even on rocky or steep coasts.

Country	City	Start	Machine type	Pipe size	Drive length	Geology	Remarks
USA	Clarksville, Virginia	1992	AVN600	DN 766	50m	sandstone, rock mixture of clay and silt	water intake into a lake for a power plant
Germany	Europe	Feb 94	AVN3000	DN 3000	2,535m	sand,clay	landfall for a gas pipeline
Hungary	Czepel	2009	AVND2000AB	DN 2425	270m	sand, clay, marl	Danube river outfall
England	Ramsgate	Feb 94	AVN1200	DN 1200	530m	sand,limestone	sea outfall
England	Horden	1999	AVN1800	DN 1800	550m	sand, clay, limestone	sea outfall
Portugal	Porto	Jan 96	AVN1600	DN 1600	520m	sand, granite	sea outfall
England	Horden	May 97	AVN1800	DN 1800	550m	sand, clay, limestone	sea outfall curve
Spain	San Sebastian	October 99	AVND2000	DN 2000	410m	rock	sea outfall
France	Biarritz	April 03	AVN 1200T	DN 1400	400m	rock, sand	sea outfall
Spain	Zujar (State)	Feb 03	AVN1600	DN 1600	208m	clay, gravel	intake / lake
USA	Wrightsville, York, Lancaster River	May 04	AVN1200TC	DN 1500	2x 115m	rock, slate	water intake/ river
USA	Greenville, Table Rock	June 04	AVN1200TC	DN 1500	150m	rock, black slate	water intake embankment/ lake
Spain	La Coruña Camariñas	June 04	AVND2000	DN 2400	200m	rock, mixed geology	water intake ocean
Spain	San Pedro Del Pintar	Dec 04	AVN 1200	DN 1400	625m	soft rocks	sea outfall
Spain	San Sebastian, Mompas	April 05	AVND2000	DN 2000	1000m	limestone, rock	sea outfall
Spain	San Pedro Del Pintar	Feb 06	AVND2000	DN 2000	1150m	sand, clay	sea outfall

France	Sables Dolonnes	March 2006	AVN1500TB	DN 1500	630m	sand, rock,weathered rock	sea outfall
Norway	Mongstad	Nov 2007	HDD, HK250T	DN450 / 18"	300m	rock, hard granite	landfall for a gas pipeline
France	Cote d Azur, Nizza	April 2007	HDD, HK150C	DN 850 / 34"	115m	weathered rock	sea outfall
Indonesia	Borneo	2005-2006	HDD, HK250T	DN 600-800 / 24-32"	1900m	limestone, clay	landfall for a gas pipeline
Portugal	Praia de Mira	2008	AVND2400AB	DN 3000	2 x1,500m	silty sand	water intake for a fish farm
Portugal	Praia de Mira	2008	AVND2000AB	DN 3000	2 x1,350m	silty sand	water intake for a fish farm
Spain	Ibiza	2008	AVN800-A	DN 1200 / 48"	215m	gravel, sand	landfall gas pipeline, sleeve pipe for HDD
New Zealand	New Plymouth	2007	AVN800-A	DN 1200 / 48"	2 x220m	gravel, sand	landfall oil pipeline, sleeve pipe for HDD
Australia	Otway Bay	2006	AVN800-A	DN 1200 / 48"	248m	gravel, sand	landfall oil pipeline, sleeve pipe for HDD
Australia	Brisbane, Tugun	2007	2 x AVN2800AH	DN 2800	2x2,000 m	rock, 100 Mpa	intake for desalination plant
Australia	Sydney	2008	AVND2000AB	DN 2525	830m	sand	sea outfall
Australia	Adelaide	2010	2 x AVN2800AH	DN 3440	1 x1,396m, 1 x1,060m	rock (200MPA), sand	intake for desalination plant
New Zealand	Christchurch	June 2007	AVND1800AB	DN 1800	875m	silt, sand, gravel	sea outfall
New Zealand	Duneden, Tahuna	Feb 2007	AVN1500TB	DN 1500	535m	rock, sand, clay, gravel	sea outfall
Brazil	Santos	Sep 2008	AVN1500TB	DN1810	726m	sand	sea outfall
Brazil	Salvador	2009	AVN1800TB	DN 2145	446m	medium to hard rock	sea outfall

Marocco	Rabat	April 2009	AVND2200AB	DN2665	800m	sand, rock	sea outfall

Table 2: Reference list sea outfall/ water intake structures built with Herrenknecht equipment (summary)