Trenchless installation methods have less impact on the environment and the existing infrastructure than other methods such as open cut trenching. Pipelines that are laid underground are better protected against damage and therefore have a higher life expectancy than those laid above ground. For the installation of sea outfalls and seawater intakes, Pipe Jacking/Microtunnelling, Segment Lined Tunnels and Horizontal Directional Drilling (HDD) methods may be applied depending on the site and ground conditions, pipe diameter and length to be installed, as well as on constructability and economic factors.

With the exception of relatively few, nearly all metropolitan areas in the world are located next to coastal waters. In addition, more than half of the world’s population currently lives within 60 km of a coastline. Therefore, tunnelled outfall constructions are often an effective and sustainable way to improve the quality of life in coastal areas.

With the help of sea outfalls wastewater can be transported away from the coastline and discharged at locations where diffusion, dispersion and decomposition are enhanced. The municipal wastewater may be fully treated, pre-treated or untreated.

Seawater intakes can also be constructed, for example, to supply water to desalination or power plants. If no beach or sandy floor exists near the plant location, or if the site conditions are inadequate for infiltration, a tunnelled offshore intake system may be an ideal choice.

Conventional methods of pipe installation for outfalls have usually required the pipe to be prepared on site and either pulled or floated into position and then sunk to the seabed and anchored, usually a less environmentally-friendly option.

The main benefits of trenchless installation methods when compared to open cut trenching include:

a) Minimal impact on the environment due to:
   - minimal surface disruption,
   - no deterioration of sea water quality,
   - lower emissions.

b) Minimal impact on the existing infrastructure, therefore:
   - applicable in high density urban areas,
   - no disturbance of tourism,
   - no limitation of shipping traffic.

c) Higher lifetime of the pipeline due to:
   - less risk of settlement, higher seismic safety
   - cyclonic weather conditions
   - protection of pipeline, e.g. against damage by ships

d) Less influence of environmental conditions, e.g. weather and hydraulic conditions like ebb, flood, storm, sediment transport.

e) Minimal efforts for the reinstatement of site after finishing the installation.

Pipelines laid on the sea bottom are directly influenced by hydrodynamic forces resulting from currents. Typical currents caused by orbital movements of wave particles and near-coast currents can damage pipes especially during heavy seas or storms. Hydrodynamic forces cause erosion, transport and accretion of seabed material. Offshore structures in general influence the currents and may lead to heavy erosion or accretion near the structures. Pipelines laid on the sea bottom may also increase the current velocity and thus turbulence. A two-phase flow of sand and water under the pipeline can form and scour may develop, which depend on the following parameters: the vertical current velocity profile, turbulence, wave reflection, bed material and bed roughness.

If the pipeline is laid directly on the sea bottom, scouring can lead to a large free span of the pipeline between two supports. If the pipeline is laid on concrete supports, the scouring may cause...
the supports and the pipeline to sink. The bending radius of the pipeline between two supports may be exceeded and pipeline may break.

**PIPE JACKING/MICROTUNNELLING TECHNIQUES**

As an example of the technique, let’s look at the pipe jacking method being applied to a sea outfall on a steep coast. The pipe is made of reinforced concrete and has an internal diameter of 2.0 m and the length of the individual jacking pipes is 3.0 m. The length of a submarine outfall or intake tunnel is generally between 500 and 1,200 m. Let’s also assume the jacking machine chosen is a Herrenknecht AVND2000AB with a length of 9.3 m and an approximate weight of 40 t.

Over the last 50 m of the route, the pipe segments have to be securely connected in order to minimise uneven settlement and to withstand forces when flooding the tunnel. The end pipes of the tunnel, when installing the diffusers may have to be ballasted with solid ballast to avoid buoyancy. All barges required for the offshore works have to be adequately moored, so that they can withstand the forces resulting from currents and machine operation during recovery.

A start pit is excavated at the landward side of the pipeline. The dimensions and the design of the start pit may vary according to the specific requirements of the site with economics being a key factor. A thrust wall is constructed to provide a reaction against which to jack. The initial alignment of the pipe jack is obtained by accurately positioning guide rails within the thrust pit on which the pipes are laid.

Powerful hydraulic jacks are used to push the jacking pipes through the ground. At the same time, excavation is taking place within a steerable shield. The Herrenknecht remote controlled microtunnelling machines are operated from a control panel in a container which is located on surface next to the start shaft. This is an advantage regarding safety regulations, because no staff has to work in the tunnel during construction. The position of the shield is supervised by a remote controlled guidance system. As the jacking forces increase during the installation of the pipe due to the skin friction and the length of the installed pipeline, intermediate jacking stations may be installed to reduce and distribute the jacking forces, thereby reducing the forces applied by the main hydraulic jacks in the start pit and secondly on the thrust wall. The seaward end of the pipeline is closed with a bulkhead equipped with a valve. Construction tolerances are in the range of <30 mm.

A reception pit of sufficient size for removal of the jacking machine is established by using a dredging pump at the sea side end of the drive. The spoil is stored on a transport barge and transported to a dumping area by the barge.

A barge with a crane is moored at the position from which the jacking machine shall be recovered. The jacking machine is equipped with lifting eyes on its upper side. The crane is connected to the lifting eyes of the jacking machine by means of a spreader beam. The connection has to be carried out with the help of divers. The jacking machine is lifted to the barge by the crane. The barge or a ship can transport the jacking machine to the land.

A barge is moored at the position from where the jacking machine shall be recovered. The jacking machine is equipped with lifting eyes on its upper side. A spreader beam is connected to the

*A schematic of the recovery of the microtunneller from the reception pit.*
barge via a rope and then to the lifting eyes of the jacking machine with the help of divers. By deballasting the barge, the jacking machine is lifted up. Water level fluctuations caused by ebb and flood may be considered to increase the lifting height. If necessary, the lifting height may also be adjusted by a winch placed on the barge. The barge or a ship transports the jacking machine to a harbour, where the jacking machine can be removed by a high-capacity crane.

The diffusers may be a separate pipe unit with several pre-mounted smaller diffusers or they may be directly mounted to the corresponding reinforced pipe segments.

SOUTH BAY OCEAN OUTFALL
At the US-Mexican border, a 3.35 m diameter tunnel has been constructed 45 m below the ocean floor. This tunnel extends 4.3 km offshore. A 2.74 m diameter riser conveys the treated effluent to a 1.6 km pipeline anchored to the ocean floor. Ultimately, two diffuser legs of 600 m discharge the effluent in water of up to 28 m depth. The outfall system with a design capacity of 1.5 million m³/d accommodates waste from the South Bay International Wastewater Treatment Plant and the San Diego wastewater treatment facilities and eliminates pollution from the Tijuana River during storm events. Building a part of the outfall within bedrock avoided the impact the construction would otherwise have had on an environmentally sensitive estuary. It also helped overcome concerns of ocean floor placement which traverses several active fault zones. The sea floor pipeline is engineered to provide stability in the event of an earthquake.

DIRECT PIPE
The Direct Pipe® method combines the advantages of the well-established construction methods Microtunnelling and Horizontal Directional Drilling (HDD) and thus opens up new application potentials. Geological ground conditions, specified time and costs targets are the decisive criteria for the selection of the most suitable technology.

The Direct Pipe Method allows the excavation of the borehole and the simultaneous trenchless installation of a prefab and tested pipeline in one single continuous step. Similar to pipe jacking, the soil is excavated with a so called Direct-Pipe-Machine. The position along the specified tunnel route is monitored by state of the art techniques of controlled pipe jacking. The excavated material is removed through the slurry circuit placed in the prefabricated pipeline. The forces which are necessary for pushing the pipeline are exerted by a novel push mechanism known as the Pipe Thruster, an innovation of HERRENKNECHT AG. The pressure necessary for tunnelling is transmitted to the cutter head via the pipeline. This technology can used also for the application of Sea Outfalls or Intakes.

Overview of a Direct Pipe® jobsite.
Technical advantages of the Direct Pipe System include:

- Single-phase mode of operation.
- Permanent borehole support.
- Borehole collapse breaking the surface is thus not possible.
- The cutting wheel can be equipped for any geological condition.
- Excavated material is transported safely out of the borehole by conveyor lines, sedimentation in the borehole is not possible.
- Curved routes can be tracked, precise to the centimetre, thereby avoiding excessive bending stress on the pipeline and excessive laying forces.
- Operations at the target pit only to dismantle the cutting head.

Economic advantages include:

- Limited work areas required at the launch pit and target pit.
- A minimum volume of slurry is required.
- Due to a very small overcut a minimum borehole diameter can be realised, thus minimizing the amount of excavated material.
- Boring time can be reduced, no coupling times are necessary and the pipeline can be laid continuously in one single step.
- No permanent protective piping/casings are necessary.

HDD

The Horizontal Directional Drilling (HDD) method can also be applied to seawater intakes, outfalls for sewage discharge and landfalls for oil, gas or telecommunication pipelines. There exist two options regarding construction method and drilling direction depending on conditions:

The drilling can start from the landward side with the rig located at the coastline. In this case the product pipe would be floated, connected to the drilling pipe at sea and pulled by the rig to landward start site.

Otherwise drilling starts from offshore with the rig being installed on a barge or jack-up platform. In this case, the product pipe can be pre-fabricated, assembled, connected with drilling pipe at the landward exit point and pulled by the rig to the offshore position.

The offshore facilities have to be designed to withstand hydrodynamic forces as well as forces resulting from machine operation.

Pipelines are corrosion protected by a fibre glass reinforced epoxy coatings or by polypropylene coating. For the welds fibre glass reinforced epoxy coating is easier to handle than polypropylene.

If drilling is to be carried out from a modified jack-up platform, this platform is moved to the position from where the drilling shall be carried out. The modified jack-up platform is equipped with all necessary drilling equipment and has a moon pool, through which drilling is carried out. The drilling rig is placed on the jack-up platform relative to the entry point of the drilling into the sea bottom. The sleeve pipe is held in place by suspensions mounted to the jack-up platform by sheaves.

The product pipe is pre-fabricated onshore and stored on supports of different heights in order to maintain the bending radius. The drilling rig and all other necessary facilities, e.g. drill pipes, storage facilities for the drilling fluid, containers, are placed on the jack-up platform. For the given pipe diameter and drilling length, a sufficient pulling force is necessary. The jack-up platform has to be designed to withstand this force. If the jack-up platform cannot withstand the pulling force an additional anchoring system has to be installed.

Drilling starts with a small diameter pilot bore. The direction of the pilot bore is controlled, so that the pre-determined pipeline route is kept with a tolerance of between a few centimetres to meters according to the site conditions.
After the pilot bore has reached a length of about 80 m, a wash over pipe is advanced in rotary mode until it is about 30 m behind the drill bit. Several reaming steps have to be carried out in order to enlarge the borehole. A pull back pipe is added behind the reamer. The reamer is pulled towards the drill rig.

Once the borehole has reached the dimensions necessary for the product pipe, the reamer is connected to a swivel attached to the towhead of the product pipe. The drill rig is used to pull the product pipe into the pre-formed hole. The drilling fluid will remain in the annulus and protect the pipe.

Once the towing head of the product pipe is just above the sea bottom, the sleeve pipe is pulled so that the shackle which connects the swivel to the product pipe can be removed by a diver. The pullback pipe with the reamer is pulled to the platform.

After construction of the pipeline the installation of the intake or outfall structure starts.

CONCLUSIONS

Herrenknecht microtunnelling techniques allows construction of long sea outfall pipelines which can be jacked deep under the sea bottom – in nearly every geological and topographic condition. Herrenknecht equipment is well suited for rock and mixed soil conditions also under groundwater. Horizontal Directional Drilling and tunnelled outfalls installed with segment lining or pipe jacking technique are independent of coast, even at a rocky cliff line or steep coast tunnelled outfalls are practicable. Website: www.herrenknecht.com