



Figure 1. Soft head.

Since December 2007, Ward and Burke Construction Limited have successfully designed and constructed over 4000m of pipeline using Herrenknecht's AVN range of slurry shield microtunnel boring machines (Table 1, p.18). This article by Brien G. Curran, Bryan A. McCabe and Michael J. Ward provides an overview of the microtunnelling process and showcases the potential for its use in Ireland

# Microtunnelling

## the future for pipeline construction?

Tunnel boring machines (TBMs), used in conjunction with the pipe jacking process, can provide tunnels with internal diameters varying from 300mm to 3m. Slurry machines are the most versatile type of TBM for variable ground conditions. Cost certainty, environmental benefits and technical reliability are the main reasons why this method has grown in popularity worldwide as a means of installing sewage, gas and water conveyance networks.

This is particularly true of gravity systems in busy urban areas where traditional open-trench methods can cause excessive traffic disruption, long-term damage in roadways, and cannot be used under buildings. Microtunnelling allows the utility engineer to overcome the topographical obstructions which limit the open cut trench approach.

### Pipeline construction using microtunnelling

There are four key operations involved in the construction of a pipeline using the slurry-based microtunnelling process:

#### (i) Shaft construction

Circular precast or in situ concrete caissons are generally preferred for the launch and reception shafts, due to their inherent strength and because they can serve as permanent manholes once tunnelling works have ceased. Temporary sheet-piled cofferdams are employed in certain instances when complex permanent structures are required. In addition to the external earth and hydrostatic pressures, the shaft must be capable of withstanding the jacking forces, which, for example, may be as high as 5200kN for the AVN 1200 (1200

refers to the internal pipe diameter in mm). The caissons should incorporate a soft eye (weak section of concrete) and a watertight seal for TBM entry to and exit from the shaft.

The smallest possible shaft is normally constructed for economical and technical reasons, especially in built-up areas; for example, the AVN 600 (2.2m in length and 0.76m in external diameter) requires minimum internal diameters of 3.2m and 2.4m for the launch and reception shafts respectively. This results in a confined working area but facilitates quick and efficient construction. It should be noted that the ability to construct a tunnel to a horizontal radius affords some flexibility in the choice of shaft position.

#### (ii) Excavation at the tunnel face

Excavation at the tunnel face is achieved by a rotating cutting head powered by a hydraulic motor. The TBM has the option of a soft, mixed or rock head, depending on the ground conditions (see Figures 1, 2 and 3). Scraping teeth are used to shear soft soils, cutting discs used to split rock and boulders (up to a compressive strength of 250 MPa), and mixed ground conditions require a combination of both. Openings in the head allow the excavated material to enter a crushing cone, where the rotation of the cutter head supporting arms, relative to the inner face of the machine, creates a grinding action. This crushes any large rock, cobbles or gravel pieces to 30mm in size for hydraulic transportation away from the head of the tunnel.

#### (iii) Removal and disposal of the excavated material

Water-based slurry is pumped to the head of the TBM (at a pressure slightly above hydrostatic groundwater pressure) where it mixes with the excavated material. The slurry mixture is pumped back to the surface where the spoil is removed in the separation plant through a series of vibrating screens, hydrocyclones or centrifuges, to allow reuse of the water. Tight control of the slurry pressure is essential, since it is used to support the excavated face and balances groundwater pressure; a large pressure could cause hydrofracture of the ground whereas a low pressure could lead to groundwater drainage.

In permeable soils, the formation of a mud filter cake at the face is necessary to prevent the loss of slurry into the ground, thereby resulting in the loss of face pressure. Bentonite is added to the slurry to aid the formation of this cake and has been used in many drives to date in gravel or where boulders have been encountered.

Many challenges were faced during the construction of the Bord Gáis pipeline in loose sandy gravel containing boulders under the Blackwater River in Co. Cork. The cover to the bed of the river was as little as 2.85m in places due to the tunnel's curvature in the vertical plane.

Careful control of slurry flow and timely adjustments to its viscosity along with constant monitoring of face pressure were therefore crucial to ensure minimal over-excavation and prevent hydrofracture of the cohesionless ground. Other drives, in equally challenging conditions, have been completed to date including several in Mullingar, Co. Westmeath and the Bride River crossing (near Fermoy, Co. Cork).

#### (iv) Provision of a tunnel lining

The lining consists of a 'train' of pipes pushed behind the TBM from the launch shaft by a set of hydraulic jacks. Concrete pipe manufacturers provide for a range of diameters typically in 300mm increments, all to Class H designation. The tunnel service lines are disconnected each time a concrete pipe is added. Automatic valves in the machine isolate the head during this process and a pressure sensor displays the stable hydrostatic groundwater head for the TBM operator. Intermediate jacks are used in long drives, where push pressures are constrained by the capacity of the jacking frame or the strength of the pipes in axial compression.

Bentonite is used as a lubricant to reduce jacking forces and allow drive lengths to be maximised reducing shaft and tunneling mobilisation costs. It also prevents water ingress to the overcut and supports the excavation, minimising surface settlement. The bentonite is pumped into the 20mm overcut through three ports at the back of the machine and automatic bentonite stations, located in every third pipe behind the machine. This allows the operator to control the distribution of the lubricant. Several drives, up to 216m in length, have been completed to date without the need to use intermediate jacks due to proper lubrication control.

Precise laser-guidance systems allow pipelines to be jacked to accurate line, grade and curve. The precision of the guidance system has been demonstrated by the successful completion of the aforementioned drive under the River Blackwater, along a vertical curve of 600m radius, and a drive along a horizontal curve of radius 300m for a sewage scheme in Skibbereen, Co. Cork. The radius of the curve is governed by the allowable joint deflection and length of the product pipe.

### Site investigation

A thorough site investigation (SI) is always essential in all geotechnical contracts, but there are a number of benefits to having a good

(continued on page 20)

Figure 2. Mixed head.



Table 1: Recent Ward and Burke microtunnelling contracts.

Machine	Ground Conditions	Notes	Depth (m)	Length (m)	Advance Rate (mm/min)	Site
AVN 600 (SH)	Silt	Under Streets	4.2	82	-	Skibbereen, Co. Cork. Sewage Scheme.
	Silt	Under Streets	4.2	58	26	
	Silt	Under Streets	4.2	62	-	
	Silt/Gravel	Greenfield	4.2	62	-	
	Silt/Gravel	Greenfield	4.2	102	-	
AVN 600 (SH)	Contaminated Sand	Under Streets	2.1	40	-	Enfield, Co. Meath. Sewage Scheme.
	Contaminated Sand	Under Streets	2.2	50	-	
	Contaminated Sand	Under Streets	2.1	40	10	
AVN 600 (MH)	Gravel	Under Streets	3.52	85	-	Ashbourne, Ratoath and Kilbride, Co. Meath. Sewage Scheme.
	Gravel	Under Streets	3.2	44	-	
	Gravel	Under Streets	3.67	90	-	
AVN 600 (MH)	Gravel	Greenfield	3 - 5	95	18	Lower Liffey Valley Regional Sewage Scheme. Kilcock, Co. Kildare.
	Gravel	Greenfield	4.5 - 5	107	21	
	Gravel	Greenfield	4.5	107	27	
	Gravel	Greenfield	5	107	-	
	Gravel/Clay	Greenfield	4.5	114	23	
	Gravel/Clay	Greenfield	4.5	88	24	
AVN 600 (MH)	Gravel/Sand	Under Streets	3	22	9	Athboy, Co. Meath. Sewage Scheme.
	Gravel/Sand	Under Streets	3.1	14	12	
	Gravel/Sand	Under Streets	2.9	57	24	
	Gravel/Sand	Under Streets	2.9 - 3.6	84	-	
AVN 600 (MH)	Gravel	Under Streets	3.9 - 4.5	104	-	Bunclody, Co. Wexford. Sewage Scheme.
	Gravel	Under Streets	2.9 - 4	90	-	
AVN 600 (RH)	Rock/Clay	Under Streets	7.05	60	-	Lower Liffey Valley Regional Sewage Scheme, Leixlip, Co. Kildare.
	Rock/Clay	Under Streets	5.56	25	-	
AVN 900 (SH)	Silt	Greenfield	6.1	127	-	Skibbereen, Co. Cork. Sewage Scheme.
	Silt	Greenfield	6.1	102	27	
	Silt	Greenfield	6.1	84	35	
	Silt	Under Ilin River	3	49	41	
	Silt/Gravel	Under Ilin River	3	90	43	
	Silt/Gravel	Under Ilin River	3	48	40	
AVN 1200 (SH)	Silt	Under Ilin River (hc) (2xI)	6.3	220	8	Skibbereen, Co. Cork. Sewage Scheme.
	Silt	Under Streets	6.3	140	-	
AVN 1200 (MH)	Gravel/Boulders	Under Streets	3.05	108	10	Mullingar, Co. Westmeath. Regional Sewage Scheme.
	Gravel/Boulders	Under Streets	3.90	62	15	
	Gravel/Boulders	Under Streets	4.12	50	21	
	Gravel/Boulders	Under Streets	4.05	47	19	
	Gravel	Under Streets	5.74	66	24	
	Gravel	Under Streets	5.05	73	-	
AVN 1800 (MH)	Gravel/Marl	Under Streets and Railway	3.44	117	15	
	Gravel/Clay	Under Streets	3.42	216	12	
AVN 1200 (RH and MH)	Rock	Under River Boyne	6.63	48	11	Navan, Mid-Meath Sewage Scheme.
	Gravel	Under Streets	3.45	87	24	
	Gravel	Under Streets	3.25	56	22	
AVN 1200 (RH and MH)	Rock	Under Araglin River	2.89	30	21	Curraleigh to Middleton Gas Pipeline, Fermoy, Co. Cork.
	Rock/Gravel	Under Bride River	3.10	30	15	
	Gravel/Sand	Under Blackwater River (vc)	varies	156	8	
AVN 1200 (RH)	Rock	Under Streets	4	60	-	Leixlip/Ballycoolin Co. Kildare, Sewage Scheme.
	Rock	Under Streets	4	60	-	
AVN 1200 (RH)	Rock	Under Road/Bridge	2.43	25	-	Corofin, Co. Clare, Sewage Scheme.
AVN 1200 (RH)	Rock	Under Streets	4.98	67	7.2	Lower Liffey Valley Regional Sewage Scheme/ Maynooth Co. Kildare
	Rock	Under Streets	4.83	96	6.3	

IJ: Interjack hc: horizontal curve vc: vertical curve SH: Soft Head MH: Mixed Head RH: Rock Head

SI which are particular to the microtunnelling process. It dictates the choice of cutter head, and drive and reception shafts can be constructed where changes in soil type have been identified so that the TBM is not exposed to different types in a single drive. Similarly, the depth of the tunnel can be adjusted at the design stage to ensure the tunnel heading does not straddle two soil types, causing the machine to rise where the lower stratum is composed of primarily stiffer soil.

The selection of an inappropriate cutting head for the ground conditions may result in the head becoming stuck, causing unwanted delays and, in severe cases, requiring an additional shaft to recover the machine. In other situations, the use of the water-based bentonite as a lubricant may prove detrimental, causing swelling of stiff plastic clays increasing the frictional forces, resulting in failure of the drive. The cost of a good site investigation is usually low compared to the cost of rectifying problems such as those mentioned above.

### Monitoring and research

Research is underway at the National University of Ireland, Galway to ascertain which factors have the greatest influence on microtunnel boreability for various ground conditions encountered in Ireland. To this end, a large amount of monitoring and testing has been undertaken in conjunction with Ward and Burke Construction Limited on each of the drives completed to date to help improve the efficiency of the microtunnelling process.

The machine control container is equipped with sensors, which record distance, jacking force, cutting torque, steering and direc-



Figure 3. Rock head.

tional tendency. Cutter wear, surface settlement along the tunnel alignment (where possible) and downtime are recorded manually. Relationships are being investigated between the parameters which reflect the mechanical effort of tunnelling and appropriate geotechnical parameters. Classification and testing on rock includes bedding angle, fracture spacing index, abrasivity, unconfined compressive and Brazilian tensile strengths. Index tests, gradings, shear strength and permeability data are among relevant measurements for soil sites. These relationships will form the basis for predicting and optimising TBM performance for new drives. Forward planning is vital; for example, the force required to jack the TBM needs to be known as it has a major bearing on drive length and the need for, and location of, intermediate jacking and lubrication stations. Microtunnelling provides an efficient method of installing pipelines at a time when cost is of primary concern. In the aftermath of large tunnelling successes such as the Dublin Port Tunnel, it also provides an opportunity for the Irish geotechnical industry to continue to develop expertise in this area, for domestic use and for export. Some important experience has been gained over a variety of ground conditions to date, but the challenge remains to be able to predict with accuracy the mechanical effort required for microtunnelling and to deploy the process as efficiently as possible.

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