WARD & BURKE
MICROTUNNELLING

1.0 Micro Tunnelling – An overview

Micro tunnelling (also known as slurry pipejacking) is not a new method. It is preformed extensively across the world with rapid expansion every year. Herrenknecht, manufactured in Germany, now provide robust machines to overcome difficult ground conditions. The tunnelling equipment essentially comprises of the AVN 1200 tunnel boring machine (TBM), the control container, the jacking frame, the separation and water circuit equipment, and the various ancillary equipment such as hydraulics and bentonite lubrication system.

- The AVN 1200 TBM has the advantage of being a closed face method of construction which significantly reduces the risk of losing the face stability. The TBM uses slurry pressure in conjunction with the jacking force to maintain tunnel face stability and prevent over excavation. The slurry pressures will be constantly monitored during the drive by both the tunnel operator and the engineering staff to ensure that the slurry pressure is meeting the in situ stresses acting on the face of the tunnel boring machine and therefore, preventing over excavation. This method also has the advantage of the operator being above ground at the launch pit. A simple schematic diagram can be seen in Figure 1 and a description of the various tunnelling plant can be found on the following page.

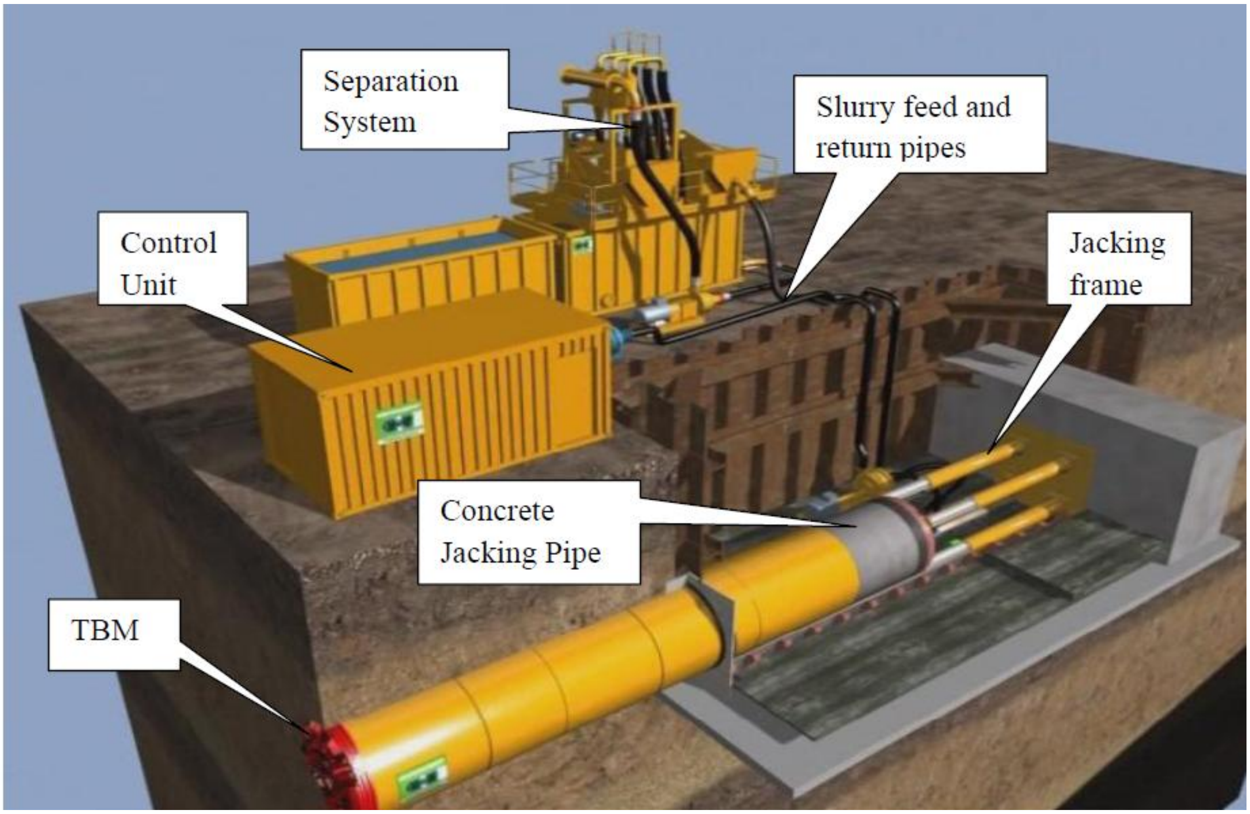

Figure 1: Schematic diagram of tunnelling equipment

- The Herrenknecht – AVN – standard range covers all the components for unmanned pipe jacking. These components are optimally designed for use together and enable safe and efficient tunnelling, whether under groundwater or not, without any accompanying action such as groundwater level lowering, provision of compressed air or freezing. The compact construction of these systems makes them ideally suited for use in heavily built up areas.
- The Herrenknecht Microtunnelling systems consist of four main components: AVN Microtunnelling machine, control container including guidance system, jacking frame and slurry pumps and settlement tank including water circuit. Additionally, Bentonite pumps and high-pressure water jet pumps can become part of the system depending on requirements.

- The CONTROL CONTAINER is the heart and brain of the entire system. In its back section, it houses the hydraulic power pack and electric distribution panels for powering all of the equipment supplied with the system. The power pack consists of powerful and separate pumps for cutting wheel, jacking frame and interjack stations, steering cylinders and slurry bypass system. The pumps are mounted on top and around a generous hydraulic oil tank and ample oil cooler. The main and sub-distribution panels supply not only the power pack but also the entire control station and operator panel, laser and ELS guidance system, bentonite pump and mixer, thyristor controlled variable speed slurry pumps, and mono-rail crane. In its front section, separated by a sound insulated wall, is the operator's control station for remote operation of the Microtunnelling machine. The controls include all functions like operation of equipment and colour monitor for ELS guidance system.

- The JACKING FRAME is of a unique space saving design. Due to its three-stage ratchet system it builds competitively short. For instance, a total stroke of 3 m requires only a cylinder stroke of 1 m. The operation starts with the (red) push block being pulled back almost to the very end of the jacking frame. Here the first set of ratchets catch the push block. Once the cylinders are fully extended, the rams are pulled back while the push block stays in place. Now, the second set of ratchets catch the push block, and a new stroke can commence. This process is repeated one more time until the entire length of pipe is installed in the ground and a new section of pipe is lowered into the jacking frame by an excavator.

- The AVN Microtunnelling machine or CUTTING HEAD is the workhorse of the system. Pushed by the jacking frame and the installed pipes respectively, it excavates the soil with one of its various cutting wheels driven by powerful hydraulic motors, obviously frequency controlled. One of the key features of Herrenknecht Microtunnelling machines are its fast adaptation to different ground conditions. Different cutting wheels that fit the same cutting head are available for sand, clay, gravel, solid rock and mixed face conditions and can be interchanged within the hour.

- The excavated material enters from the face of the cutting wheel into the crusher chamber lying behind. In there, all particles including boulders are crushed down into smaller pieces between the powerful crusher bars. During this process, water is pumped into the crusher chamber through various selectable openings inside the crusher cone, forming a slurry that can be pumped to the surface. Standard high pressure water jets help and assist in this task especially in clay.

- The cutting head in itself is articulated by hydraulic steering cylinders inside, allowing the machine to be controlled in line and grade. Therefore, a laser target or ELS target is mounted inside the machine. A laser with adjustable focus, mounted at the back wall of the jacking shaft, shoots a beam onto the back of the target which in combination with the ELS guidance system inside the control container determines the exact location and orientation of the cutting head. The information is transmitted back into the control container via a control cable that runs through the installed tunnel. This cable also functions as the control line between container and machine: all sensor signals, and solenoids for actuation of cylinders and valves inside the cutting head are receiving and transmitting their feed back through this one cable.

- The SLURRY SYSTEM or WATER CIRCUIT basically starts inside the crusher chamber of the cutting head. After the slurry is formed, it is pumped out by a frequency controlled slurry pump located at the bottom of the shaft. At long drives an additional tunnel pump right behind the cutting head can be added. Then, the slurry pump inside the launch pit pumps the slurry to the control container on the surface. In there the slurry passes through a flow meter allowing the operator to monitor the amount of slurry taken out of the ground in order to avoid loss of ground water or over excavation. After passing the flow meter, the slurry enters the separation system. A series of screens, hydro cyclones, and a centrifuge separates all solids in suspension and deposit them into a truck for disposal at a landfill. The solid-free water that remains in the tanks overflows into the next compartment from where it is re-used and pumped down the shaft by the feed pump, through the tunnel, to the cutting head and its crusher chamber again. As well, the feed water is monitored by a flow meter giving the operator all the information needed for successful slurry removal.

- In order to control the flow of feed and slurry water, the pumps are not only driven by frequency drives, but the cutting head itself is equipped with a bypass system. The system consists of a set of hydraulically operated ball valves allowing to direct or just circulate the flow of water, appropriate to the current situation underground.
- All Herrenknecht AVN machines are fully submersible and tested at a 100 feet head of water (3 bar). For special requirements, bulkheads can be added.
- The tunneling machine will be fitted with a mixed head to construct these tunnels.

3.0 Launch seal and Jacking Frame Installation

- Once the shafts are completed, the line of the tunnel is set out. The TBM needs an eye/portal to launch through. This eye will be constructed by casting a 750mm high x 1500mm dia. concrete manhole on its side in a head wall. The head wall will provide a flat surface for the launch seal to be bolted on and provide stability for the TBM during exit from the launch shaft. The eye can be removed once the drive is complete. Figure 2 shows such a headwall in operation.

Figure 2: Headwall cast and launch seal bolted to the headwall before TBM launch

- Once the headwall is complete, then the launch seal is bolted to the wall. The purpose of the seal is to minimise ground water flow into the shaft during tunnelling and hence, prevent ground movement outside the shaft.

- Once the seal is in place the jacking frame is then positioned to the required grade and alignment that the tunnel dictates.

- The gap between the back of the jacking frame and the shaft wall is then filled with concrete, ensuring a complete transfer of load to the shaft from the jacked pipes. There is a small pocket in this back wall which houses the tunnel laser that is essential for alignment of the drive (See figure 3).

Figure 3: Jacking wall and lazer

Figure 4: Working platforms in shaft

- Once the jacking frame is in position, then a platform is installed on each side to support the shaft pump, slurry hoses, and workforce (See Figure 4).

- A control room with dimensions 6m x 2.4m will be positioned at the top of the shaft so the TBM driver has eye contact with shaft activities at all times. The separation plant with dimensions 6m x 2.4m will be placed adjacent to the control container.

4.0 Launch of the TBM and tunnelling operations

- The AVN 1200 TBM will then be installed and offered up to the face of the excavation through the launch eye. The relevant slurry and hydraulic hoses will then be connected to the control unit and separation plant located on top of the shaft.

- The lowering/raising of the tunnel machine and pipes will be via a CAT 345 excavator or similar

- The cutter head of the TBM is rotated and the main jacks extended to push forward and start the excavation.

- The TBM operator controls the alignment from the target mounted within the TBM. The jacking speed and forces and slurry pressures are monitored closely to ensure no over excavation of the ground and hence, preventing ground movement.

- The TBM and trailing steel can section that is fitted behind the TBM is jacked out of the shaft into the ground while the head of the TBM is rotating. The excavated material is sent to the separation plant via the slurry circuit system. Once the TBM and trailing can section have been jacked from the shaft into the ground, the hydraulic and slurry feeds are disconnected in the shaft to allow the addition of a product pipe to the drive length. Once the pipe is in position, the hydraulic feeds for the TBM and slurry circuit are reconnected allowing for the recommencement of tunnel operations and jacking. During a pipe change, slurry valves are closed on the TBM preventing ground loss when the slurry circuit is not in use.

- It is proposed to use a 1200 id reinforced concrete jacking pipe for this project in a single pass micrtounnelling system (no open face steel liner tunnel where an inrush of water and soil could cause a sinkhole at surface level). The pipe will be provided by Munro Concrete. They are manufactured to an extremely high quality, rated for loads greater than 100D and 750T in jacking capacity. The joints are rated for water heads greater than 20m.

- The main jacks are extended to push the pipe forward until it is fitted to the pipe adapter.

- The hydraulic cables and slurry removal lines are connected, and tunnelling re-commences.

- The rotating cutting wheel excavates the material at the tunnel face and the slurry circulation system transports the excavated material to the separation plant. The slurry lines are positioned through the machine and inside the jacked pipes feeding the material back to the pump in the launch shaft. In the separation plant, the excavated material is separated from the water and the water is then recirculated.

- The slurry properties are very important for the optimal functioning of the TBM. The viscosity and density are adjusted to match the ground conditions. A dense thick slurry is required for gravel based ground to allow a filter cake formation at the face of the TBM while slurries with lower densities tend to be better at transportation of fines from the tunnel face. The viscosity and density are monitored during the drive by use of a marsh funnel and a specific gravity check. The properties of the slurry are adjusted if the ground conditions appear to change.

- The TBM overcuts to produce an annulus of 25mm around the pipeline. Bentonite is constantly pumped to the annulus between soil and pipe wall at every 6 pipes (15m) via 3no. 1 ¼ inch bentonite ports prefabricated on the pipes. The bentonite is mixed at the surface and is pumped down the tunnel to discharge into these ports. The bentonite supports the ground and also minimizes skin friction and jacking forces. Similar to the slurry pressures, the bentonite lubrication pressures are monitored closely to prevent ground heave/settlement or blowouts due to excess pressures.

- The concrete jacking pipes will be lowered into the caisson with an excavator with the required lifting capacity (CAT 328 or similar). A banksman will be at the top of the shaft and all operatives will be out of the shaft during this process. Once the pipe has been lowered into the jacking frame. Tunnel operatives will re-enter the shaft. The spigot of the lowered jacking pipe is pushed into the socket of the pipe that has been just jacked out of the caisson. This is done by vertical control supplied by the excavator and horizontal control of the jacking frame. Once the spigot of the new pipe is pushed into the socket of the jacked pipe, all ancillary services such as hydraulic lines, slurry lines, and bentonite lines are extended and reconnected. After this process, the tunnelling operations can recommence. To ensure a water and air tight seal between pipes, the spigots of all pipes lowered into the shaft will be fitted with a rubber gasket. Care is taken to ensure no damage of the gasket during the placing process.

- When the tunnel is almost completed the TBM will emerge into the reception shaft.
- Operatives will enter the front of the machine under control of a permit to enter a confined space and disconnect all hydraulic lines and cables.
- Lifting eyes are to be screwed onto existing threaded holes in the TBM. From these lifting eyes, chains are to be slung and the TBM lifted clear of the shaft using a CAT345 or greater or crane.
- Finally, the trailing tube will be jacked into the reception shaft and a product pipeline now exists between both shafts.
- The TBM is to be checked for defects and repaired if necessary. Similarly, all hydraulic and slurry lines are removed from the new tunnel, cleaned, and checked for possible defects before the next drive.
- The annular area mentioned previously between the tunnel pipe and soil will be filled with a cement based grout. 750kg of cement for every 1000 litres of water. The pressures generated during pumping of the grout will dictate the volume pumped in to ensure no ground heave. The grout prevents any possibility of settlement from the closing of the annulus between the pipe and the soil. The grout is pumped into the annular area using the same ports that were used in the bentonite lubrication process. Once grouting is finished, the 1¼ inch holes are plugged permanently with GB plugs and they are to be finished with concrete so as to mask their existence.

5.0 Management of pipes, water, and muck during drive

- A small pipe stock will be placed adjacent to the shaft with enough capacity for a minimum of half a shifts work. This stock pile will be replenished twice in the day from a main pipestock in close proximity to the shaft. By using two movements per day at off peak traffic hours, it minimises disturbance in the area.

- At expected production, 12-15m per shift, the tunnelling operations will produce 45 m^3 of muck in 24 hours of mining. The muck will be stored in bins for collection on a daily basis or it will fill directly into a truck. Bins to be removed and replaced as required.
- The majority of the ground is expected to be sands, silts, and glacial tills which will produce a dry material coming out of the screening plant which can be removed by truck. A centrifuge will be on site to deal with the clay content. Therefore, the slurry water will be re circulated and will not need to be disposed of during the drive.
- The water tanks need $50m^3$ of water to fill them at the commencement of the drive. The typical water loss in the ground (through permeation) is $10\text{-}15m^3$ per day. A licensed metered standpipe will be used to fill and top up the tanks. If this is unavailable, the water can be tankered to the location.

6.0 Programme for works

5 Days initial setup – 10 to 15m per shift (20-30m per every 24 hours) during tunnelling, 3 days demobilization.

7.0 Control of tunnelling risks

- Possibility of spills
  - The microtunnelling equipment is a sealed tunnelling system using state of art equipment. All generators on site have double bunding to prevent diesel spill. The slurry fluid is stored in 6mm thick steel plate containers, making damage or spills impossible.
- Lost equipment downhole
  - The tunnelling method prevents water and soil form entering the tunnel. There is no possibility that the equipment can be lost downhole.
- Hole collapse
  - The tunnel face is a sealed system capable of working under water depths up to 30m deep. The pipe exit point in the shaft is sealed with a rubber membrane, preventing water and soil entering the shaft. Hole collapse cannot occur.

- Frac-outs under drilling path
    - The slurry feed to and from the tunnel boring machine is rigidly controlled. Prior to commencement of the works, the required slurry pressures at any given point in the tunnel alignment are calculated based on the in situ stresses at tunnel level. The feed and return slurry flows are monitored in the controlled container through digital flow meters. The flow down is matched to the flow back to ensure no overexcavation and stable pressures at the face. In addition, there is a pressure sensor built into the head of the TBM. This sensor sends information back to the control container and allows the TBM operator to control the pressures of the slurry at the face. Through the monitoring of the flows and pressure of the slurry against the design pressures required, it is impossible to for frac outs to occur. Ward and Burke always have an engineer on site together with experienced TBM operators to ensure no frac out problems.
- Excessive deviation from proposed alignment
    - The tunnel boring machine has an articulated joint incorporated into its design. The joint is articulated through the use of three (3) steering cylinders and can turn as sharply as 5 degrees. We have completed horizontal and vertical curved tunnels with our tunnel boring machines with a radius as low as 250m and it is possible to go lower. The position of the TBM is controlled by a laser and target guidance system known as ELS. The target feeds the positioning information of the TBM to the TBM operator in the control container. If the TBM has a tendency to drift towards a direction off the proposed alignment, the operator can easily and quickly steer against the drift. Deviation from the proposed alignment of less than 25mm is easily achieved and in most cases our deviation is less than 10mm from the proposed through material ranging from hard rock to soft clay with shear strengths less than 20kPa.
- Response to settlement or heave
    - Settlement can only occur if the machine is over excavating or the slurry pressure is less than in the situ stresses. As stated above, the slurry pressures required are evaluated before the drive commences and monitored throughout the drive through full time engineering supervision. With control of the slurry flows and

pressures, volume losses less than 0.5% are easily achieved. In our previous contract on Gore road tunnelling under a 1800mm id high pressure watermain, we were able to achieve settlement values less than 1mm with 1.5m of clearance between our TBM and the water main. Similar to settlement, heave is controlled by slurry pressures and correct excavation. It is generally, a far easier property to controlled in comparison to settlement as it would take gross miss use of the equipment to engage heave in the ground. We have never experienced this problem in our 120 tunnel microtunnelling experience.

- Damage to installed pipe
    - The pipe used for jacking is a reinforced concrete jacking pipe. It is extremely robust and is capable of withstanding jacking forces of 1000T (our jacking frame has a 500T capacity). We operate a sophisticated automatic pipeline lubrication system, where the flows, pressures, and location of the lubrication into the pipeline can be controlled through a computer programme. Therefore, our jacking forces are extremely low. We generally can push a 200m long tunnel with 100T of jacking force. Our skin friction coefficient for all ground types range between 0.5 to 2 kPA through the use of this system. Through the use of the excessively strong jacking pipe and the low jacking pressures, we have never experienced pipeline failure.
- Possibility of encountering shale or mixed face conditions.
    - The TBM head is designed to work through mixed face conditions. The machine would maintain line and grade if a mixed face of shale and glacial till was encounterd.