Tunnel boring machine

Tunnel boring machines (**TBM**) excavate tunnels with a circular cross section through a variety of rock strata. They can be used to bore through hard rock or sand and almost anything in between. Tunnel diameters can range from a metre (done with micro-TBMs) to 15 metres. The two biggest were built in 2005 to dig two tunnels for the same urban project in Madrid (Spain). Dulcinea and Tizona, as they were called, have diameters of 15 metres.

Tunnels of less than a metre or so in diameter are more typically done by horizontal directional drilling rather than by TBMs.

Tunnel boring machines are used as an alternative to drilling and blasting (D&B) methods. A TBM has the advantages of not disturbing surrounding soil and producing a smooth tunnel wall. This significantly reduces the cost of lining the tunnel, and makes them suitable to use in built-up areas. The key disadvantage is cost. TBMs are expensive to construct, difficult to transport and require significant infrastructure.

Description

A tunnel boring machine (TBM) typically consists of one or two shields (large metal cylinders) and trailing support mechanisms.At the front end of the shield a rotating cutting wheel is located. Behind the cutting wheel there is a chamber where, depending on the type of the TBM, the excavated soil is either mixed with slurry (so-called *slurry TBM*) or left as-is. The choice for a certain type of TBM depends on the soil conditions. Systems for removal of the soil (or the soil mixed with slurry) are also present.

Behind the chamber there is a set of hydraulic jacks supported by the finished part of the tunnel which push the TBM forward. The action here is very much like an earthworm. The rear section of the TBM is braced against the tunnel walls and used to push the TBM head forward. At maximum extension the TBM head is then braced against the tunnel walls and the TBM rear is dragged forward.Behind the shield, inside the finished part of the tunnel, several support mechanisms which are part of the TBM can be found: dirt removal, slurry pipelines if applicable, control rooms, rails for transport of the precast segments, etc. The cutting wheel will typically rotate at 1 to 10 rpm (depending on size and stratum), cutting the rock face into chips or excavating soil (muck). Depending on the type of TBM, the muck will fall onto a conveyor belt system and be carried out of the tunnel, or be mixed with slurry and pumped back to the tunnel entrance. Depending on rock strata and tunnel requirements, the tunnel may be cased, lined, or left unlined. This may be done by bringing in precast concrete sections that are jacked into place as the TBM moves forward, by assembling concrete forms, or in some hard rock strata, leaving the tunnel unlined and relying on the surrounding rock to handle and distribute the load.

Shields

Modern TBMs typically have an integrated shield. The choice of a single or double shielded TBM depends on the type of rock strata and the excavation speed required.

Double shielded TBMs are normally used in unstable rock strata, or where a high rate of advancement is required. Single shielded TBMs, which are less expensive, are more suitable to hard rock strata.

Urban tunneling and near surface tunneling

Urban tunneling has the special challenge of requiring that the ground surface be undisturbed. This means that ground subsidence must be avoided. The normal method of doing this is to maintain the soil pressures during and after the tunnel construction.

There is some difficulty in doing this, particularly in varied rock strata (imagine tunnel boring through a region where the upper portion of the tunnel face is wet sand and the lower portion is hard rock).

TBMs with positive face control are used in such situations. There are three common types: Earth pressure balance (EPB), Bentonite slurry (BS), and compressed air (CA). The compressed air method is the oldest, but is falling out of favour due to the difficult working conditions it imposes.

Both types (EPB and BS) are clearly preferred over open face methods in urban environments as they offer far superior ground control.When tunneling in urban environments other tunnels and deep foundations need to be addressed in the early planning stages. The project must accommodate measures to mitigate any detrimental effects to other infrastructure.

History

The first successful tunnelling shield was developed by Sir Marc Isambard Brunel to excavate the Thames Tunnel in 1825. However, this was only the invention of the shield concept and did not involve the construction of a complete tunnel boring machine, the digging still having to be accomplished by the then standard excavation methods.

The very first boring machine ever reported to have been built was Henri-Joseph Maus's *Mountain Slicer*. Commissioned by the King of Sardinia in 1845 to dig the Fréjus Rail Tunnel between France and Italy through the Alps, Maus had it built in 1846 in an arms factory near Turin. It basically consisted of more than 100 percussion drills mounted in the front of a locomotive-sized machine, mechanically power-driven from the entrance of the tunnel. Unfortunately, the revolutions of 1848 irremediably affected the funding of the project and the tunnel was not completed until 10 years later, by using also innovative but rather less expensive methods such as pneumatic drills.

In the United States, the first boring machine to have been built was used in 1853 during the construction of the Hoosac Tunnel. Made out of cast iron, it was known as *Wilson's Patented Stone-Cutting Machine*, after its inventor Charles Wilson. It managed to drill 10 feet into the rock before breaking down. The tunnel was eventually completed more than 20 years later, and as with the Fréjus Rail Tunnel, by using less ambitious methods.

In the early 1950's, F.K. Mitry won a dam diversion contract for the Oahe Dam in Pierre, South Dakota, and consulted with James S. Robbins to dig through what was the most difficult shale to excavate at that time, the Pierre shale. To that purpose, Robbins built a machine that was finally able to cut 160 feet in 24 hours in the Pierre shale, which was ten times faster than any other digging speed known at that time. The breakthrough that from then on durably made tunnel boring machines efficient and reliable was the invention of the rotating head, conceptually based on the same principle as the percussion drills head of the *Mountain Slicer* of Henri-Joseph Maus but improving its efficiency by reducing the number of grinding elements while making them to spin as a whole against the soil front. Initially, Robbins' tunnel boring machine used strong spikes rotating in a circular motion to dig out of the excavation front, but he quickly discovered that these spikes, no matter how strong they were, had to be changed very frequently as they broke or tore off. By replacing these grinding spikes with longer lasting cutting wheels this problem was significantly reduced. Since then, all successful modern tunnel boring machines have rotating grinding heads with cutting wheels.