MACHINE TUNNELING

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STATE OF THE ART

Machine tunneling, as used in this discussion, refers to underground excavation whereby the ground in its original state and position is disintegrated by milling, scarifying, or crushing with a power-driven tool. Several types of tunneling machines are in use today. These include the well-known "mole," which uses a rotating cutter head to bore a circular tunnel; the road-header machine, which has a smaller rotating milling head mounted on a randomly controlled boom; and the powerful backhoe excavator-scarifier, which is also mounted on a boom, the motion and position of which are controllable from an operator's station.

Excavation of rock by milling is not a new concept. In 1880 an Englishman by the name of Beaumount designed a machine that successfully bored 3.2 km (2 miles) of a tunnel 2.1 m (7 ft) in diameter through chalk for investigation of the proposed Channel Tunnel. During the 1920s, the coal mining industry did a considerable amount of experimental work with continuous mining machines, most of which incorporated the principle of the chain saw.

In 1947, James Robbins, a mining engineer, designed a continuous mining machine based on the idea of using roller cutters to operate on the outstanding rings of coal left in the face between the grooves or kerfs formed by the drag bits.

In 1952, Robbins, working in conjunction with Mitty Construction Company, built a tunneling machine for boring the 7.8-m (25 2/3-ft) diameter diversion tunnels for Oahe Dam on the Missouri River in South Dakota. The material there was Pierre shale, a soft rock quite similar to the Bearpaw shale, which had been successfully cut with coal saws at Fort Peck Dam several years earlier. That machine made a good record, advancing as much as 49.1 m (161 ft) in a single day. It proved that soft rocks could be excavated with a continuous boring machine and was so successful in the shale at Oahe Dam site that, before that project was completed, subsequent contractors on later tunnel contracts there purchased three more boring machines of similar design.

Moles are today the most commonly used tunneling machine. Improvement in roller cutting wheels has constantly progressed until it has become possible to cut rock whose strength is 207 MPa (30 000 lb/in^2) or more. As rock strength and hardness increase, however, the cost of tool replacement rises steeply and the rate of advance decreases.

The rotating head machine requires that a great thrusting pressure be applied to the rock face. This thrust is accomplished by use of hydraulic cylinders bearing on gripping devices against the tunnel perimeter or against structural tunnel supports that are erected as the bore progresses. When boring under favorable conditions, a mole is capable of average sustained advance rates of 1.5 to 3.0 m/h (5 to 10 ft/h). Record 24-h runs of 91.4 to 121.9 m (300 to 400 ft) have been reported.

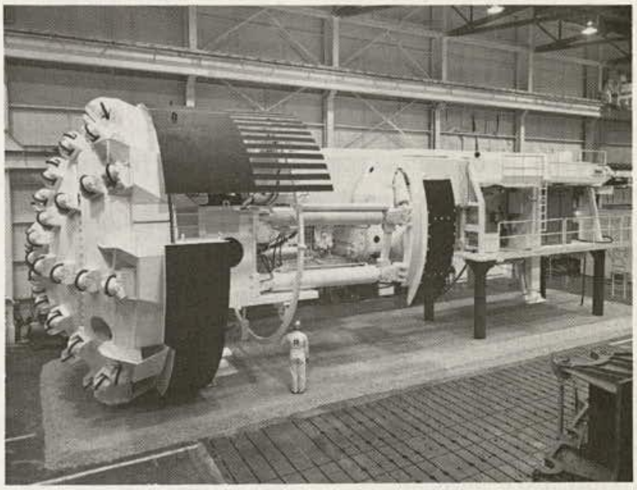
There have probably been more than a hundred types of mole tunneling machines designed, fabricated, and put into service throughout the world since the first one at Oahe Dam in 1954. The art is developing rapidly.

Foreign manufacturers of these machines have reported success in recent years with fully shielded machines using precast concrete segments for tunnel lining in badly faulted and decomposed granite rocks where the conditions may change abruptly from fresh hard rock to running ground or to a mixed face of hard and soft rock.

The road-header machine has had greater acceptance in Europe than in America. It consists of a rotating milling head studded with hard-faced teeth or picks. The head is on the end of a hydraulically positioned boom capable of applying the cutter to any desired spot on the face or perimeter of the chamber. The machine, usually mounted on crawlers, is strongly powered and can exert great pressure between the revolving wheel and the rock. Fragments that are removed by the cutter fall to the floor and are removed by means of a mechanical gathering device feeding a conveyor. Road-header machines are capable of excavating soft and medium rocks with strengths to 138 MPa (20 000 lb/in^2).

Random arm backhoes have been used successfully on several American tunnel projects. This type of excavator can only be used in ground that can be ripped. When working in suitable formations, the ripper-backhoe machine is often capable of rapid advance because its digging bucket becomes an effective tool for gathering and removing the loosened muck.

Tunnel boring machine (photo courtesy of Robbins Company).



FUTURE RESEARCH

Bits and Rollers

Considerable private investigation has been and will continue to be done into effectiveness of cutting bits and rollers. Sufficient potential for profit probably exists to make such research worthwhile to a manufacturer. Additional publicly funded studies might contribute toward faster production and lower unit cost of cutters.

Working Face Access

Tunnel boring machines tend to perform well as long as they are penetrating uniform material free from geological abnormalities or excessive inflows of water. Characteristically, however, the interception of bad ground by machines that are designed for use in good, self-supporting rock causes a cessation of machine boring and initiation of conventional hand-mining methods. Most boring machines are concentrated masses of machinery that occupy the entire tunnel cross section and effectively block access to the face when new excavating methods must be adopted. Attention might be directed toward rearrangement of the machinery for easier access to the working face.

Ground Sensing Studies

Knowledge of ground conditions in the region ahead of the face is important. Drilling of advance exploratory holes is slow and costly. More studies should be carried out into sensing of ground conditions by electronic or other subtle physical means.

Machine Versatility

General purpose tunnel boring machines will likely be developed that can cope with practically any ground condition. The urgency of geological prediction will thereby be reduced. Researchers should strive to improve machine versatility.

Slurry Use

In Japan, England, and Germany, a considerable amount of development work has been done on tunnel boring machines that use slurry within a confined space surrounding the cutter head. The Japanese have had experience with many of these units and have reported performances as high as 276.5 m (907 ft) of a tunnel 5 m (16 ft 7 in) in diameter in 1 month. No machine of this type has been built or used in the United States.

Concrete Segment Liner

In the United States, no soft ground tunnel has been constructed in which precast concrete segments are used as a final liner. Other countries have all but standardized on this type of support. American engineers should be encouraged to examine this type of construction.

Flexible Tunnel Size

Many people have recommended that tunnels be standardized in size. Perhaps the better approach would be for design engineers to consider accepting flexibility in tunnel size rather than standardization. As an example, the designer may require a tunnel with a minimum diameter of 3.8 m (12½ ft), but would be willing to accept a larger diameter at the option of the contractor up to, say, 4.3 m (14 ft) in order to obtain a low bid from the contractor who has a tunnel boring machine capable of achieving a 4.2-m (13¾-ft) diameter hole.