THE MOLE

A new approach to tunnelling in Australia

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Tunnel Boring machines have been used extensively in America in recent years and have achieved spectacular results. During 1960 the firm which developed the machines in America, J.S.Robbins and Associates, successfully tendered for a contract to supply the Hydro-Electric Commission of Tasmania with a unit to drive the Poatina tailrace tunnel, as part of the Great Lake Power Development Scheme. The machine was to drive a 16ft.1in. dia. tunnel, 14,400 feet long, through Quamby Mudstone, one of the hardest rocks yet attempted by Robbins' machines. Tests carried out on this rock indicated compressive strengths of up to 12,000 p.s.i. and that also numerous harder inclusions ranging in size up to three feet in diameter could be expected.

Description of Model 161

(a) General

Basically the Mole consists of a large rotary cutting head on which is mounted both fixed and rolling disk cutters. Behind the cutter head are hydraulically-operated gripper-shoes which provide torque reaction and propulsion cylinders which keep the required cutting pressure against the tunnel face.

Rock crumbling from the face as a result of pressure and torque applied to the cutting head is scooped up by four buckets fixed to the rotating head periphery. When the buckets become inverted the rock falls through an opening in the cutter head on to a conveyor-belt which passes it back to the rear of the machine and then on to a Dixon Conveyor.

Photo (i) shows the Mole during assembly at Poatina. The buckets have still to be bolted over the openings shown on the head. The thrust cylinders and the side grippers can be seen.

(b) The Cutting Head

The cutting head weighs approximately twenty tons. It rotates at 5.52 r.p.m. in a clockwise direction, being driven by six 415-volt Louis Allis motors, via a ring gear. Timken roller bearings with a B.10[1] life of 10,000 hours are used as the main head bearings. Thirty-four roller cutters are mounted on the head, eight of which act as gauge cutters. The rolling cutters are mounted in sealed bearings, B.10 bearing life being 2,000 hours. These cutters are of cast steel, with the cutting edge hard faced.

[1] A standard requiring 90% of the bearings to equal or exceed the specified rating

Thirty tungsten-tipped fixed cutters are mounted near the centre of the head, since the cutting radius becomes too small for roller cutters to work effectively.

This cutter arrangement is that of the   hard rock" type used successfully on Model 131 for tunnelling through hard, crystalline limestone. An access door is provided in the cutting head to enable the cutters to be examined for wear and replaced when necessary. To carry out this operation the head has to be withdrawn from the face approximately 18 inches.

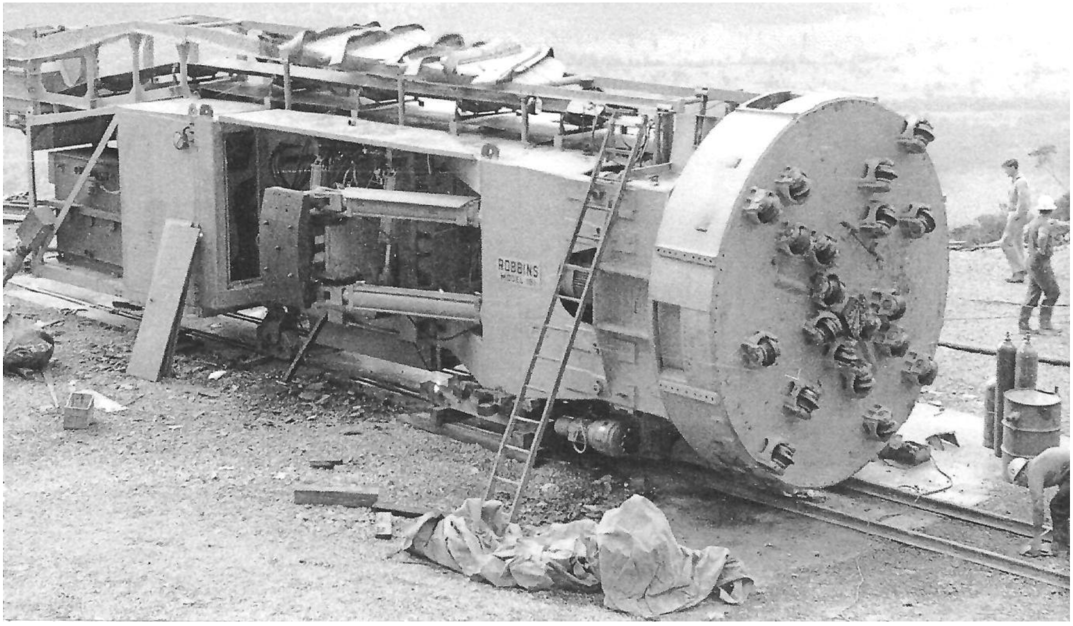

Photo (i): Model 161 during assembly at Poatina

Photo (ii) was taken through the access door with the head withdrawn. The large number of circles towards the centre is the pattern from the fixed cutters. The larger circles are the points of contact of the roller cutters.

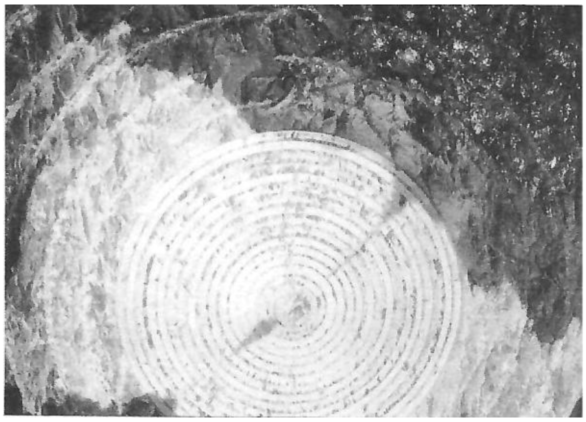

Photo (ii): Cutter pattern on rock face

(c) Machine Operation

(i) Boring and Setting Up

The total weight of the Mole is approximately 100 tons. Apart from the electrically-driven cutting head and belt conveyor, all other machine movements are hydraulically operated. The hydraulic system has been designed for 5,000 p.s.i., which necessitates the use of special hoses and fittings. The Mole travels without rails, but track is necessary for the spoil haulage.

While boring, the weight of the machine is carried by side grippers thrusting on the tunnel wall and by a front support shoe behind the cutter head. The axial thrust is obtained from thrust cylinders which move the whole machine forward relative to the side grippers. The Mole can therefore bore for a distance equal approximately to the length of the thrust cylinders which is referred to as the stroke of the machine.

At the end of a stroke, approximately 3ft. 9in., rear supports are lowered and the side grippers retracted. The thrust cylinders now act in reverse and draw the side gripper assembly back along the machine. The side grippers are then thrust out on to the tunnel wall and the rear support shoes retracted. The machine is then ready for the next stroke.

(ii) Steering

The direction of tunnelling can be controlled from the steer shoes at the front of the machine and also from the gripper assembly if necessary. Situated behind the cutter head are three hydraulic cylinders, two of which can move the head either left or right, while the third, which also acts as the front support shoe previously mentioned, can raise or lower the head.

The Mole can also be rotated about its longitudinal axis by means of torque reaction cylinders connected to the gripper assembly, or by the rear support shoes which are individually controllable.

(iii) Performance

Most of the information contained in this section was collected over 1,250 feet of tunnelling, from Ch. 472 to 1,672 feet. For the purpose of estimating rates of advance and costs, the following rock classifications were adopted:

Class A" – Strong rock requiring no support, mesh and bolts only to prevent fretting

Class" B" – Rock which will stand until permanent sets can be erected and bolted from behind the Mole

Class C" – Rock which fails before permanent sets can be erected. Some overbreak occurs which requires timber packing

Class D" - Rock which fails at the tunnel face. Some heavy sets required.

Rock Classification	A and B	C	D
Average Advance – 8 hour shift	21,8 ft	6.4 ft	3.5 ft
Mole Operating Time	52%	25%	16%
(i) Normal Tunnelling Delays	17%	6%	Negligible
(ii) Boring Equipment Delays	28%	5%	4%
(iii) Delays Owing to Weak Rock	3%	64%	80%

(i) Normal Tunnelling Delays

This includes delays caused by the connection of services and spoil haulage. The major cause of delay here was the addition of ventilation pipes which takes approximately 15 min. for each pipe.

(ii) Boring Equipment Delays

This includes scheduled Mole maintenance and repairs, and also the Dixon Conveyor maintenance. Scheduled Mole maintenance is carried out on each day shift, taking approx. three to four hours. The head is pulled back from the face for cutter examination and any necessary cutter changes are then made. At the same time the Mole conveyor assembly is pulled out to clean spillage from under the head pulley.

(iii) Delays Owing to Weak Rock

(a) *In class "B" rock* – These delays were caused by the installation of temporary or permanent sets.

(b) *In class "C" rock* – Temporary sets with mesh and occasional timber packing were stood immediately behind the cutter head. Sometimes rock movements would occur before these sets could be stood. At the rock bolting platform the temporary sets were then replaced with permanent ones, covering 90 deg. or 270 deg., depending on rock conditions.

Further delays occurred due to slipping of the conveyor belts in wet conditions and the jamming of large rocks in the hopper throat. In this rock cutters rarely need attention but the Mole can suffer serious mechanical damage. The side steer shoes project into overbreak and can then be sheared off. To guard against this the dust shields are removed and the steer shoes observed and packed if necessary.

(c) *In class "D" rock* – 360 degree, 6 in. x 5 in. I-beam permanent sets were installed ahead of the grippers. Overbreak occurred on the tunnel sides and packing was required to enable the side grippers to obtain sufficient bearing pressure. Where side gripper bearing pressure was inadequate for safe operation a safety cut-out addressed the risk of Mole body rotation. In soft zones the front support shoe of the Mole sunk up to 12 inches below grade. Packing back to grade was necessary. Keeping the machine on grade was further complicated here since the rear had to be kept high enough for the rear support shoes to clear the permanent sets. The damming of water by the permanent sets also aggravated difficulties in the soft invert. Power failures also occurred in this type of rock, probably owing to the partial jamming of the cutter head, since failure was occurring at the face.

Advantages of Continuous Boring

(i) *Safety* – Round, smooth, unshattered openings are inherently strong. Rockfall danger is slight and usually little or no support is necessary. This is especially important where rock is under stress. In the Poatina tailrace tunnel the main regions requiring heavy supports were fault zones and dikes. Most of the tunnel required no support, only rock bolts and mesh to prevent fretting.

(ii) *Blasting Damage* -Since no explosives are used, boring eliminates damage to rock bolts and to the crown and walls. In strong rock boring leaves a smooth finish, while in weak rock, as in fault zones, even though a small amount of overbreak may occur, it will not be as great as that which would occur from blasting.

(iii) *Economy* – The Mole costs approximately £220,000 and writing this off on the tailrace tunnel it is expected that excavation costs will be approximately equal to, or slightly less than, those by conventional methods. The greatest saving by using the Mole is in the reduction of concrete required for tunnel lining. The overall saving is expected to be £110,000.

Conclusion

Drawing conclusions from the initial 6,000 ft. of tunnelling the Mole has proved successful, both in its ability to tunnel through the hardest rock yet attempted, and to tunnel economically. From its poor performance in the fault zone, a tunnel boring machine would be unsuitable for a project requiring tunnelling through extensively fractured and water-logged rock. It would appear that tunnelling in harder rocks still by boring machines would be practical but probably not economical owing to possible high cutter maintenance costs and slow advance rates.

Footnote

Latter information received from the Hydro-Electric Commission, Tasmania, indicates that the Mole completed the 14,400 ft. tailrace tunnel in 56 weeks, the average advance being 259 ft. per week.

However, after 6,300 ft. it was necessary to withdraw the machine for a major overhaul of the lubrication system, main drive and bearing and this occupied 12 weeks which is included in this time. After tunnelling was recommenced the final 8,100 ft. was driven at an average rate of 415 ft. per week.

Best short-term performances are:

Best 8 hour shift – 48 ft.

Best 24 hour day – 122 ft.

Best 6 day week – 554 ft.

One mile – 12.2 weeks

Despite some very bad ground and one encounter with a 30 ft. dike of dolerite, the Mole completed this tunnel in excellent time, setting a new world record for any size of tunnel, viz., 751 ft. of excavated and supported tunnel in six days.