Chapter 17

THE BLUE MOUNTAINS SEWERAGE SCHEME
A CASE HISTORY OF THE HAZELBROOK TO KATOOMBA TUNNELS

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ABSTRACT

This project, which is intended to provide effective sewerage services to the Blue Mountains community, is located in the Blue Mountains National Park, about 60 km west of Sydney, Australia. The sewerage scheme consists of about 40 km of tunnels, out of which approximately 22 km have been completed.

This paper describes the last major tunnelling operation on this project, the Hazelbrook to Katoomba tunnels. These tunnels, which mainly traverse the Hawkesbury Sandstone formation, are being excavated by a new 3.4 meter diameter Jarva Mk12C TBM. The mucking system consists of a continuous conveyor, which has allowed for some very impressive advance rates.

The paper will consist of three main sections; the general geological conditions expected along the tunnel will be described in the first section. The second section will discuss the design and main features of the TBM, back-up system and continuous conveyor. The third section of the paper will describe the operational aspects and various performance data of the machine.

INTRODUCTION

The Sydney Water Board has been working on the further development and upgrading of the sewerage systems of the Blue Mountains since the early 1980's. The main thrust of this plan has been to provide effective sewer services to the community and to protect natural streams by high quality treatment of the sewage. Since the community lies within a National Park, the plan also pays close attention to the preservation of vegetation and the environment in general. The Water Board has developed objectives which guide the sewage system development. The existing system, cannot without significant improvements meet these requirements.

The new plan calls for the redirection of sewage, through a series of tunnels to a central upgraded treatment plant at Winmalle, and the decommissioning of a number of smaller local treatment plants. The total length of tunnels required is approximately 40 km.

This paper deals with the remaining 18 km, or more specifically the 16.9 km TBM bored portion of the project. This section consists of two tunnels, both 3.4 m in diameter. The first, which is currently under construction is the 13.4 km long Katoomba carrier. The second portion is the 3.5 km long Lawson carrier. Of he remainder, 1.3 km will be constructed with a road header and a short 150 m section will be completed with drill and blast.

The contract also includes some nine ventilation and drop shafts of either 1.5 or 3.0 m in diameter, between 60 and 150 meters in depth. These shafts were sunk blind prior to the tunnel excavation.

The Joint Venture of McConnell Dowell of Australia and Obayashi of Japan was awarded the project in June of 1993. It is being built as a Build-Own-Operate-Transfer (BOOT) scheme and is privately financed. Upon completion the JV will sell the civil works to a second party which will operate the facilities and charge the Sydney Water Board a fee for it's use.

GEOLOGY

The geology of the Blue Mountains National Park is a part of the Triassic Sydney Sedimentary Basin. As the name implies, the rocks are of sedimentary origin, with sandstones and claystones being most prevalent. The overall project encompasses four main formations. These are the Hawkesbury Sandstone, the Burralow formation which consists of finer sandstone, the Wentworth Falls Claystone and the Banks Wall Sandstone.

The Hazelbrook to Katoomba sections lie for the most part within the Banks Wall Sandstone formation which underlies the ridges in the upper parts of the Blue Mountains. The sandstone consists of medium to coarse Quartzsose sandstone. It is typically massive and competent. It is cross bedded with layers ranging from 1 to 10 m in thickness. Shale/laminate lenses, up to 3 m thick are found interbedded in the sandstone. Thin iron stone zones, up to 30 cm thick are commonly found as well.

Joint frequency at the tunnel levels is fairly low and no large faults or igneous intrusions have been found at the tunnel alignment. The test results of bore samples indicated the UCS values for the Hawkesbury sandstone to range from about 10 to 80 MPa where some of the higher values are attributed to ironstone.
The TBM has been boring in material in the upper part of this range, mainly from 50 - 80 MPa.

TUNNEL BORING MACHINE

In June of 1993 the Joint Venture selected a new Robbins MK12C TBM for the tunnel excavation. It was to be delivered in December later that year. This was the first TBM sold by Robbins after its merger with Atlas Copco MRE and the first machine incorporating technologies and engineering input from both organizations.

The MK12C can be said to consist of three main components; the cutterhead, the working and the gripping sections. In addition the hydraulic, lubrication and electrical systems provide the power for the machine operation. Figure 1. below shows a section view of the machine and it's main components.

Cutterhead

The cutterhead is a sturdy steel fabrication , the front part of which consists of a very thick steel plate to ensure the structural stiffness required to evenly distribute the thrust to the cutters for optimal cutting efficiency and cutter life. The front face of the cutterhead is machined to insure a uniform height of all cutters and the cutter housings, which are of the wedge lock type, are welded to this machined face. The cutterhead is divided into a center section, carried by the main bearing of the TBM and four detachable spokes.

Scraper blades are located on the spokes to scoop the muck into the buckets mounted at the rear of the cutterhead, and a rock breaker is provided for crushing large chunks of rock before they are loaded into the buckets and then onto the conveyor.

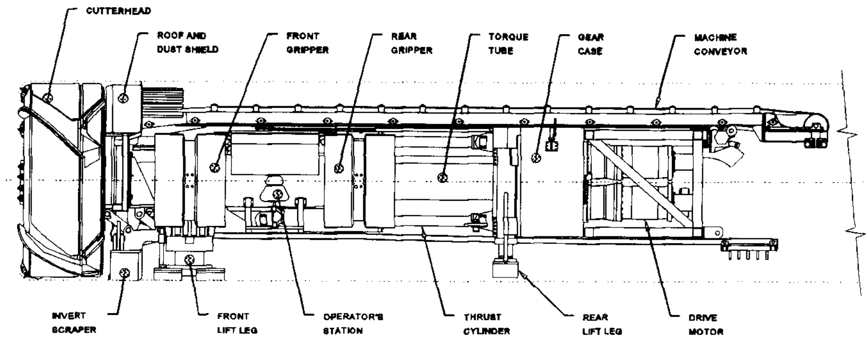

Figure 1. Jarva MK 12C

Working Section

The working section consists of the bearing housing, torque (reaction) tube, the drive train, the rear lift legs and the muck conveyor. The torque reaction tube is a rigid structural member which is supported by the main body and connects the bearing housing to the gear case.

Cutterhead rotational torque is developed by four electric motors located at the rear of the machine. Each motor is rated at 250 kW and drives a 2-stage planetary gearbox with a pinion on its output shaft. The pinion drives a common ring gear which turns the cutterhead via the drive shaft which runs through the center of the torque tube.

Cutterhead thrust is developed by the thrust cylinders. They transmit this thrust from the main body through the gear case and the torque tube. This is accomplished by retracting the cylinders which have the cylinder ends pinned to the main body and the piston rods to the gear case housing at the rear end of the TBM.

Gripping Section

The gripping section consists of a main frame and four grippers attached to the front and rear of the main body in the horizontal plane. The front lift leg lies in the same vertical plane as the front grippers, together forming a T-pattern, seen from the rear.

Adjustable bronze slide bearings with an automatic greasing system support the working section in and transmit the torque reaction to the main body. Sliding the working section on bronze reduces friction. This means that almost all of the available thrust goes into the cutters for boring rock, without friction losses.

The grippers are individually controlled and the gripper pads are mounted by means of a ball joint, so that they will automatically seat uniformly against the tunnel wall, thus eliminating point loading which could cause tunnel wall rock failure.

The cutters are of the extended tip wedge lock design. These cutters are designed for relatively soft abrasive formations and the extended tip provides more wear volume and hence longer life. The machine however, has the thrust capacity to load each cutter 254 kN. So for future projects the machine can be equipped with a higher load rated cutters intended for harder formations.

General Specifications

The general specifications of the TBM are listed below Table 1.

Table 1. Jarva MK 12C Specifications.

Diameter	3.4 m
Cutter Size	17" (432 mm)
Load Capacity	222 kN
Number of Cutters	25
Cutterhead Thrust	6,350 kN
Cutterhead Power	1,000 (4x250) kW
Cutterhead Torque	763 kNm
Cutterhead RPM	12.5
Machine Weight	170 tons

BACK-UP SYSTEM

The back-up system was designed and built by Terratec, an Australian Company. It is specifically designed to incorporate the continuous conveyor. The total length of the system is approximately 106 m. Features of interest include conveyor erection deck where conveyor structure and idlers are inserted into the system, a complete lunch room for 12 people and replacement of the usual bridge conveyor by the main conveyor belt.

CONTINUOUS CONVEYOR

The tunnel conveyor has been designed to operate in conjunction with the TBM and its service train to continuously remove spoil generated the machine to a waste pile beyond the tunnel portal. The relatively small tunnel diameter required the conveyor to be mounted in the crown rather than the side wall as is more common.

The conveyor is continuously extended in length as tunnel construction proceeds by the addition of 3 m long modules suspended form the roof. These modules are installed at the rear of the back-up system. Additional conveyor belt is added periodically to a loop storage system. This system also acts as an automatic take-up for control of conveyor belt tension.

As the length of the conveyor increases tripper drive units are added, both on the carry and return sides of the conveyor. Ultimately, including the initial drive unit installed adjacent to the belt storage, a total of six drive units were installed.

The conveyor is required to negotiate a number of horizontal curves through the length of the tunnel. Provisions are made in the suspension of the conveyor stringer modules to allow super-elevation of the stringers on the inside of the curve for correct tracking of the loaded belt. Side guide idlers are provided for tracking control of an empty or partly loaded belt.

As mentioned above, a total of six drive units were installed along the length of the conveyor. Initially a single drive operates the system ad is located in a fixed tripper next to the belt storage outside the tunnel. Intermediate drives are installed as the conveyor is extended. The location of the drives was determined by the build up of tension in the conveyor as monitored by load cells incorporated in each drive unit.

The intermediate drives are of a modular construction, are roof mounted and may be inserted in place of conveyor stringers at any point over the length of the conveyor. Drive components including the drive pulley, motor bearings, mounting plates, guides and scrapers are interchangeable between drive assemblies.

An eight part reeved belt storage is included. The nominal capacity of the unit is 400 m of belt. With allowances for belt take-up the maximum length of belt in the loop is about 500 m. Belt tensioning is achieved with a hydraulic winch which operates continuously to maintain belt tensions at the design value. The tension is monitored by a load cell incorporated into the winch rope reeving system. The set point for the tension can be varied. The winch is fitted with a holding brake to maintain minimum belt tensions while the conveyor is not running.

Control of the conveyor system, including the drives, the storage system and all control and safety devices, is by an electronic PLC system. A master PLC is located outside the tunnel and a slave PLC is incorporated in each drive unit. A condition monitoring and control station is provided for the TBM operator.

The belt speed is controlled to about 2.5 m/sec and this provides a maximum muck transport capacity of 250 ton/hour.

TBM OPERATION

Site Assembly

The machine was manufactured in Gothenburg in Sweden and was finished in slightly less than six months. It left on a ship bound for Australia in December of 1993. Components started arriving at the project site in late January and the assembly of the machine at the portal area was complete by mid February. The first boring stroke was completed on February 28, 1994.

Machine Performance.

The project is organized using three 8 hours shifts daily for five days a week with two production shifts on Saturdays or a total of 17 shifts per week. Each shift crew consists of 12 people. The shifts are changed at the face.

The average performance, daily meters divided by hours bored, to date has been about 8 m/hour. Actual boring time represents about 25% of the time available. In light of this and the high monthly advance rates, very high instantaneous advance rates have been achieved. The machine has on occasions bored in excess of 12 m/hour, but these are rates that are difficult to maintain. The entire boring system has however been able to handle the 8 m/hour average comfortably.

The table on the following page lists the performance from start-up through the completion of the first tunnel in January 1995.

Table 2. Monthly TBM Performance.

Month	Meters Bored
March 1994	993
April	1182
May	826
June	1290
July	1233
August	1759
September	777 [1)]
October	1584
November	1267
December	804 [2)]
January 1995	1366

1) Excavate turnoff for spur tunnel
2) Christmas Holidays

The above information is depicted graphically on the next page. Based on the above the average monthly performance for the first tunnel was 1189 m. This included two partial months.

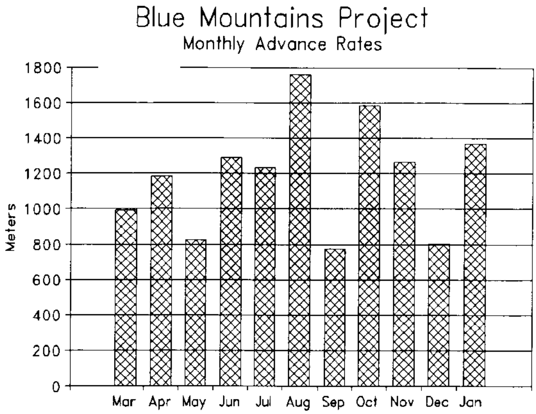

Figure 2. Monthly TBM Performance

As far as we can ascertain, several world records for a machine of this size have been broken. The following lists some of the best performance achieved to date for various categories.

Table 3. Best Performance to Date.

Eight Hour Shift	73 meters
Single Day	172.4 meters
Single Week	703.3 meters
Calendar Month	1759 meters
Four Weeks	2067 meters

To date, the machine utilization has averaged about 25%. The remainder of the time has fallen into categories as can be seen on the following page.

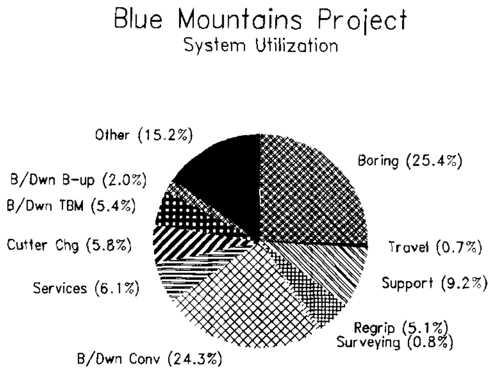

Figure 3. System Utilization

The performance to date has substantially exceeded what the Joint Venture used in planning the project and at the time of this writing the project is well head of schedule.

Ground Support

The ground support consists of a combination of resin grouted bolts, mesh, steel straps and steel sets.

Total support requirement for the first tunnel has been as follows:

No Support	15%
Patterned Bolting	45%
Bolts and Mesh	26%
Bolts, Mesh and Straps	13%
Steel Sets	1%

Final support will require the application of shotcrete of various thicknesses to the crown and wall where bolting has been required. The invert will be concrete lined to dry weather flow levels.

CONCLUSIONS

The conveyor system has resulted in significantly higher production rates than would have been possible with rolling stock.

It has to be considered as a significant equipment item requiring a corresponding level of design input, operational attention and maintenance. With machine penetration rates of 12 meters per hour possible, the primary limitation on tunnel progress has in this case become availability of the conveyor system.

The Robbins extended tip wedge lock cutters have provided excellent performance in what is a relatively soft but extremely abrasive rock. No cutter failures have been experienced and cutter rebuilds have been minimal. Cutter life has improved about 400% over cutters used in similar conditions on the other portions of this project.

The project has gone very well to date and is currently significantly ahead of schedule. It is anticipated that the second drive will proceed equally well.

REFERENCES

Putten, R. Van and McQueen, LB., 1993 "Blue Mountains Sewage Transfer Scheme - A Review of Tunnelling" Proceedings VIII Australian Tunnelling Conference, pp 9 - 19.