Rock mass rating systems:

to use or not to use?

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Foliation shear zone (Project 4).

Weak sand washed through precast segment grout holes (Project 2).

Rock mass characterisation systems are aids to improving the assessment of anticipated excavation and support conditions for underground construction. But, all too often, they have been used as a substitute for thinking, which has resulted in their misapplication and has led to construction problems, delays and cost over-runs.

These rating systems were developed as design aids for conventionally excavated tunnels and underground openings. They take into account geotechnical characteristics, such as span width and stand-up time, and operational characteristics, and have proved useful for practical assessment of anticipated support based on field experience.

Recently, however, such rating systems have been applied to bored tunnels. Although the predictions that result are not necessarily unreliable, their use implies that TBMs and their back-up systems are appropriate for the ground conditions being looked at. This may not be the case.

The Rock Mass Rating (RMR) system developed by Bieniawski[1] was recently used to predict the support needed for a tunnel excavated by TBM, with the RMR values for drill+blast increased by 10 per cent. But this did not take account of the nature of mechanical excavation and its limitations and operational considerations.

As a consequence, stability problems developed during excavation because of two unanticipated major fault zones. The instability begun by the action of the TBM's grippers at the springline spread to and over the crown, causing a collapse that required hand mining using heading and bench methods in front of the TBM.

RMR systems in bored tunnels

Rock mass characterisation systems are designed for drill+blast excavation and assume that there is no equipment at the heading or delay for support installation. They also assume forces from blasting and gravity, intact and rock mass character.

There is no easy way of adjusting RMR data collected for drill+blast tunnels to be applied wholly or reliably to TBM excavation. The support guidance given by the RMR value cannot take into account problems of TBM excavation such as:

- distance between excavation at the tunnel face and the first practical support installation behind the cutterhead;
- time delay from excavation at the face to the installation of support, which may not be consistent with stand-up time;
- ground disturbance by the machine grippers on tunnel walls (compression) and tunnel crown (tension); and
- mechanical operation being at odds with ground conditions.

Unlike the case with drill+blast, the heading is filled by the TBM and its back-up system which cannot be removed in the same way that the drilling jumbo is taken away before blasting to provide a clear work area. Operations at the TBM heading are consequently limited. Also, since tunnel boring is continuous, its operations consistent and routine, the effect of anticipated conditions on the boring system are often overlooked.

Differences in boundary conditions for drill+blast and TBM excavation should be obvious. Blasting disturbs rock and causes loosening and fallout into the opening. Mechanical boring does not disturb the blocks and fallout occurs unexpectedly after support by the cutterhead is removed. Alternatively, progressive failure may take place over an extended period of time. Also, the grippers of an open TBM induce very high localised stresses in providing the reaction for thrust and torque to the cutterhead.

All rock mass characterisation systems have limitations which are notable, for example, at the margin between soil and rock. The RMR does not apply to soil or soil-like conditions. Additional limitations of rating systems may include:

- a failure to address the fact that mechanically bored rock will appear to be better than it is, often reflected in a failure of inspectors to note poor rock conditions until after progressive failure has occurred, leading to collapse in a bored tunnel; and
- insensitivity at the lower range of values, particularly with respect to rock intact strength, RQD and rock altered to 'soil-like' material.

RMR and TBM experience

Table 1 provides data on some case histories on the use of open and shielded TBMs in a range of geotechnical conditions. Project success is relative but may be said to be where the excavation was completed without a fundamental change of method, long delay and substantial cost increases.

Project 1 was a major failure in terms of the geotechnical analysis provided for assessing support conditions for the 4.3m diameter open TBM used. The work was in a sheared and faulted zone and RMR = 8 was anticipated. But an unexpected intersection of two major fault zones was encountered. This led to instability around the opening, and support was required.

In one instance, split sets with wire mesh and strapping were installed. A collapse occurred 80-104h later. At another point a 240° ring steel was installed with a bolted invert strap. A collapse ahead of the supported section over the cutterhead occurred 8-16h later.

After the second collapse, a 100m long core was drilled ahead of the face. The characteristics of the core are summarised in Fig 1. Hand mining was used to advance the tunnel 30m ahead of the TBM.

Project 2 encountered a variety of conditions, ranging from medium hard sandstone to sand and shale, and from dry to 400 litre/s water inflow. The 3.4m diameter TBM was shielded and support ranged

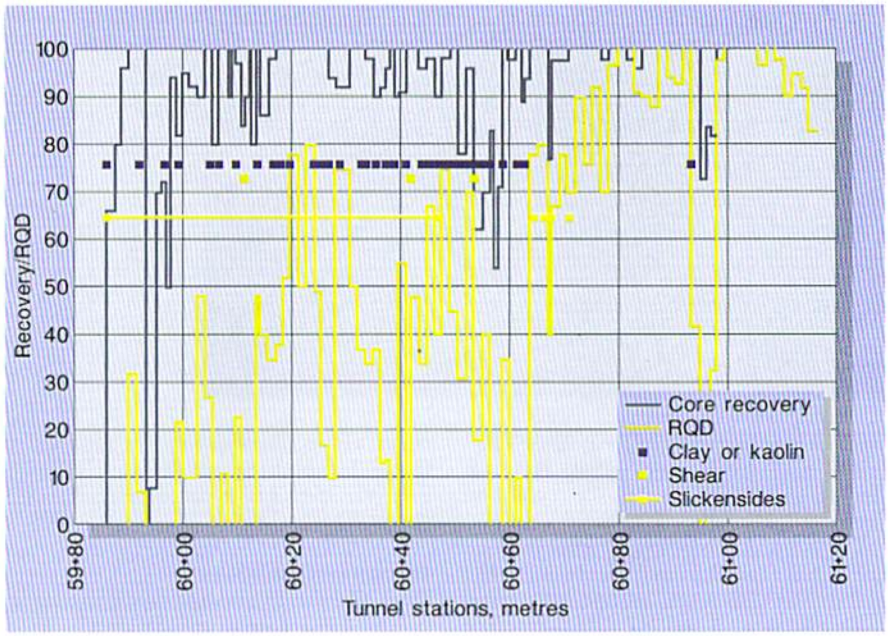

Fig 2. RMR and bored tunnels RMR.

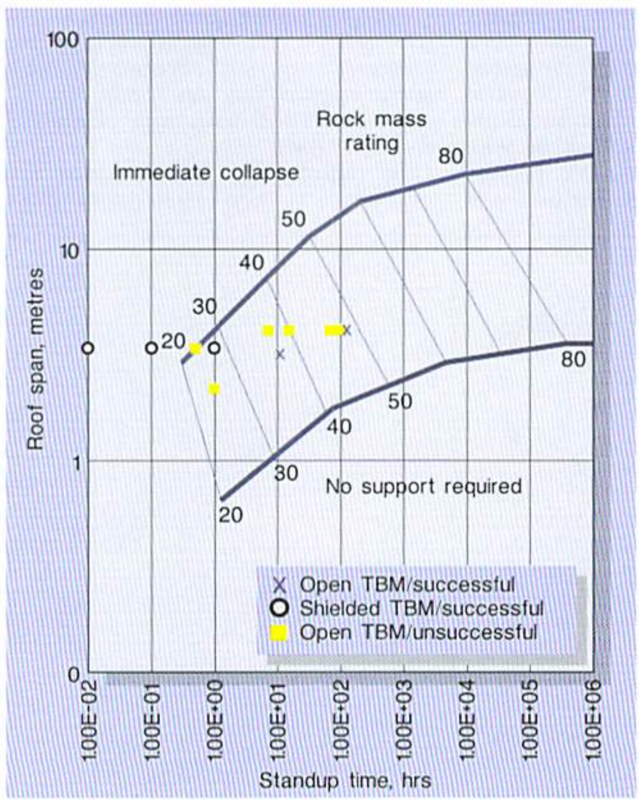

Fig 1. Probe hole characteristics.

from none to temporary precast segments behind the TBM. The water washed weak sand through pre-cast segment grout holes. The TBM managed to struggle through the various unconsolidated sands and the water inflow but with extensive delays and additional costs.

Projects 3 and 4 were bored through schist ranging from fine to coarse grained, foliated to unfoliated, and intact to fractured, jointed and faulted. Both projects used a 3.4m diameter open TBM, and Project 3 also used a 2.6m diameter open TBM.

Project 3 met a number of shear and fracture zones that slowed excavation, but these were dealt with quickly and cost effectively. But Project 4 was not a success. The TBM encountered a foliation shear zone that was completely altered to clay in the right invert. As the machine advanced, it deviated from line and grade and sank into the soft clay. It had to be backed up, realigned, and cribbing substituted for the clay to support the machine.

Project 5 was bored through shale, sandstone, and limestone that was bedded, fractured, loosened, and resulted in unus-

Maximum water inflow (Project 2).

Table1. Summary of case history data.

Project	Stand-up time, hrs	Diameter, metres Open TBM	Shielded TBM	Open TBM	RMR
1a	8.00			4.3	37
1b	16.00			4.3	40
1c	80.00			4.3	46
1d	104.00			4.3	47
1e	120.00	4.3			48
2a	0.01		3.4		0
2b	0.10		3.4		15
2c	1.0		3.4		27
3	12.00	3.4			38
4	0.50			3.4	25
5	1.00			2.3	25
6	2.00		6.1		34

ual and severe overbreak. An open TBM bored a 3.4m diameter tunnel. The contractor made a differing site condition claim and was compensated.

Project 6 used shielded TBMs through chalk that ranged from intact to fractured and dry to high water inflows. The bores ranged between 5 and 7m. All tunnels may be considered successful.

Fig 2 shows the stand-up time, roof span, and RMR values for drill+blast openings. The projects from Table 1 have been plotted to show successful and unsuccessful applications for TBMs. Shielded machines appear to have been successful in ground with shorter stand-up time. With open TBMs, success is variable, particularly at low values of RMR. The success of open TBMs depends on the alternative method chosen to get through difficult ground. Open TBMs can develop difficulties at RMR = 45.

Recommendations

Rock Mass Rating should only be used for:

- drill+blast support assessment;
- TBM support assessment for RMR>20; and
- TBM excavation feasibility assessment for RMR<45 and only with appropriate judgement, experience, assignment of risk and/or responsibility, and specific consideration of TBM design (for example a shielded TBM).

As reflected in Fig 2, extraordinary measures have been required for a TBM successfully to traverse ground with an RMR of 25 to 45.

Limiting TBM excavation to RMR>45 would be a severe restriction considering the increasing number of projects that require tunnel boring. TBMs have been designed to deal effectively with the poorest rock conditions, but owners are reluctant to specify machine designs.

Successful assessment of feasibility and application of tunnel boring excavation is possible through: responsive assessment; appropriate contract language; minimum equipment requirements; and inclusion of alternative methods and pay items. ■

References

1. Bieniawski, Z T. (1988). Engineering rock mass classifications. *Published by Wiley & Sons.*