1. Introduction

Since the 1960's when Robbins developed the first commercially successful full face rock TBMs, the main beam machine has been the lowest cost, most efficient TBM configuration. Some call these machines Main Beam, some Gripper, some open and some even call them spiders. However they are labelled, these machines hold many of the world records for tunnelling advance rates.

The Main Beam machine's advantages are simplicity and low cost of tunnel support materials. These qualities are the result of the machine's ability to use grippers on the tunnel walls to propel themselves rather than requiring a lining to push against. Avoiding the need for a lining saves the lining cost, time, and labour.

Previously Main Beam machines have had one serious handicap; if they encounter fractured rock or rock that fails they have had trouble securing the roof. Insecure roof can present safety issues and, if roof rock fails, it lays on the tunnel invert where it impedes the machine's advance and requires expensive and time consuming labour to remove it.
The traditional solution to this problem was to employ a finger shield (Photo 1). The finger shield had a number of fingers for which it is named. Using a finger shield for roof support involved placing a sheet of wire mesh under the fingers and bolting it to the tunnel roof with rock bolts installed between the fingers. A rib positioned under the mesh could be added to the system if it was felt necessary.

The hope for the finger shield was that when the fingers were pulled out from between the mesh and the rock by the TBM's advance, the loose rock which had been resting on the fingers would settle gently onto the mesh and hang safely above the tunnel until final support of the tunnel was put in place days or months later.

In practice as the fingers are removed by the advancing TBM:
- All the rock bolts become loose because they could not be tightened past contact with the fingers
- Loose rock drops a distance equal to the finger thickness until it encounters the mesh which may sag into the tunnel opening. The result is a void equal at least to the finger thickness above the loose rock. The void permits further rock fall until the bulking effect stops the failure or the mesh fails and drops the loose rock into the tunnel.
- In cases where there is significant loose rock above the tunnel mesh, rock falls into the tunnel. The resulting pear shaped tunnel can lead to face instability and increasing failure problems.

Contractors know about these main beam TBM deficiencies. Consequently they have been cautious about employing Main Beam TBMs on projects where the rock may not be uniformly good. They have instead chosen to use shielded TBMs and accepted the higher costs in exchange for reduced risk.
2. Development of the McNally System™

Recently in Toronto, C&M McNally Engineering Corp. was using a main beam TBM to bore a 3500mm tunnel in highly stressed, horizontally bedded shales. We found that because of the high stresses the rock in the roof was failing at the back edge of the cutterhead. By the time we could get supports under it, about 2500 mm back from the face, the failure was 500 mm above the tunnel. We realised that the finger shield was not going to be effective and developed what has become known as the “McNally System™”. The McNally System™ is a major advance in the art of rock support on main beam TBMs because it allows main beam TBMs with their cost and productivity advantages to perform in rock that would have been considered unsuitable for a main beam machine.

![Diagram](image)

**Figure 1.**

The McNally System™ replaces the finger shield's curved plate above the cutterhead support with a curved assembly of tubes. The tubes normally have a rectangular cross section and they reach from the cutterhead axially to the rear side of the cutterhead support. The rear edge of the tubes should correspond to the furthest forward point that roof drills can access while drilling vertically. Generally these dimensions imply that the tubes are 2500 to 3000mm long. The tubes are joined together so that their outermost sides form the outermost part of the roof support. In operation the tube assembly is in contact with the tunnel roof.

If you imagine that this tube assembly looks like a sheet of oversized corrugated cardboard pushed against the tunnel roof, you have the right idea.
3. McNally System™ Process

Figure 2.

Identification of Parts:
A. Location above/ outside cutterhead of TBM
B. First rock bolt and rib assembly
C. Subsequent rock bolt and rib assemblies
D. Rock above TBM Support
E. Leading end of roof support tube
F. First slot
G. Second slot
H. Third Slot

McNally System™ Process

Figure 2, details the process of operating the McNally System™.

Notes:
1. Slats (F) are of wood, assemblies of steel, or other material suitable for the longitudinal members of the tunnel roof support.

2. Slats are sized to fit easily into the tubes, with thickness that allows two slats to fit on top of one another inside the tubes. Slats must also be stiff enough to span between the ribs which will form the transverse structural member of the future roof support and flexible enough to flex under the ribs while being fed into the tubes.

3. Slats are longer than the tubes, long enough to ensure that the end of each slat will be pinched against the tunnel roof by a rib and pulled from its tube as the TBM advances.

4. Ribs have holes through which rock bolts are inserted. Ribs with excessive section depth will make it difficult to install slats. Channel ribs work well.

5. Sufficient bolts must be installed to prevent rib buckling.
4. Result

Figure 3.

Figure #3 shows the result of applying the McNally System™, a continuous grillage of structural members on the tunnel roof. The whole assembly held tight against the tunnel roof by rock bolts. The rock bolts also reinforce the rock mass around the tunnel. The grillage supports loose rock and confines the roof preventing it from becoming loose.
5. McNally System™ Applications

5.1 Ontario

Tunnel in Georgian Bay Shale, McNally System™, Timber Slats

Since developing this system C&M McNally has applied it while mining many kilometres of tunnel in the shales of southern Ontario. It has always provided safe tight roof support and prevented the occurrence of failing roof which had previously caused production delays and unplanned costs.

5.2 Peru

Olmos Tunnel, McNally Olmos System™, Rebar Assembly Slats

The Olmos tunnel in the Peruvian Andes is in metamorphic and volcanic rock. Due to the high cover over the tunnel (2000M) the rock around the tunnel fractures as the TBM advances. The TBM was equipped with a conventional finger shield/mesh/rock bolt system for roof control. The system was not able to contain the loose rock above the tunnel. As a result the tunnel crew was investing the majority of working time doing
supplementary rock support and invert cleanup. In 2008 the McNally System™ was installed on the TBM. The system held the fractured rock and as a result rock support time was greatly reduced. Consequently the advance rate more than doubled. The project is continuing using the McNally system.

5.3 China

The McNally System™ is being installed on a number of TBMs destined for work in China. At the time of writing no reports are available.

6. Rock Stress Management: an Advantage of the McNally System™

Boring a tunnel in a stressed rock mass causes stress concentrations around the advancing tunnel and in the tunnel face. Where these stress concentrations exceed the rock's strength the rock often fails by bursting.

Rock bursting occurs under high cover and often in the tunnel face ahead of the TBM. Bursts ahead of the TBM can delay production by causing the TBM's cutterhead to stall and have the potential to cause damage to the TBM. The cause of the rock bursts can be seen as a combination of three items; insitu stresses, rock strength, and the stress changes occurring around the advancing TBM. Clearly it's difficult to alter insitu stress and rock strength. There is though, a possibility to influence the stress increases in the tunnel face.

A tunnel face can be seen as a "pillar" keeping the tunnel sides from approaching each other, converging, in response to the rock stress field. If the newly excavated tunnel opening is free to converge, the face pillar's load is increased. Conversely, if the tunnel walls are restrained from movement the pillar's load is reduced. This suggests that reducing tunnel convergence will reducing face stress and rock bursting.

The McNally System's unique ability to maintain a circular tunnel with a confining grillage and tensioned rock bolts installed close to the face reduces convergence because it builds a rock arch that resists convergence. It is therefore likely that use of the system will reduce rock bursting.

7. Practical Issues

Practical issues that need to be addressed for success when the System is applied are; coordination, component design and training.

7.1 Coordination between TBM and Rock Support Materials

Traditionally contractors buy their TBMs from TBM makers and their rock support materials from local suppliers. Because the slats must fit into the TBM's tubes and the ribs should be installed right behind the tubes, to be successful The McNally System™ requires coordination between the TBM maker and the rock support supplier to ensure that the slats and ribs are sized correctly to allow slat installation and appropriate rib installation location.

7.2 Component Design:

The dimensions and materials for each application are dependent on the TBM, geotechnical conditions, tunnel dimensions and local material availability. Judgement needs to be applied to these issues before the project begins.

7.3 Training:

TBM crews are used to other methods of rock support. Without instruction they are not likely to understand why their new TBM has no finger shield and "tubes in the roof". Consequently, until the McNally System™ becomes more widely used it will be necessary to provide start-up training on each project.
8. Availability

The McNally System™ is covered by a US and Canadian Patents. International patents are pending. The system is marketed by The Robbins Company.

Author

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