The Risks Associated with TBM Procurement and the Next Steps Towards Industry Change

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ABSTRACT: Risk management in the world of TBM tunneling is, in itself, a risky business. The underground often presents obstacles and complex projects spanning miles of tunnel multiply those risks. However, there are ways to manage and reduce risk in our industry; i.e., by ensuring that thorough geotechnical studies are done and that contingency plans are in place. The TBM itself can be designed with risk reduction in mind, using tools that expand visualization of the ground around the machine and arm the contractor with ways to get through challenging ground conditions with minimal delays. This paper will explore risk in TBM tunneling from the viewpoints of the consultant, the contractor and the equipment manufacturer. It will also seek to make recommendations as to how risk can be better managed in today's tunneling industry.

INTRODUCTION

The majority of tunnels for civil engineering applications are now being constructed using some form of mechanical excavation. Beginning in the 1960s with rock TBMs, the tunneling industry has introduced both Earth Pressure Balance (EPB) and Slurry Pressure Balance (SPB) soil machines; Mixed Soil and Rock machines and a huge variety of different mechanical devices for the construction of small diameter tunnels. Over time, these machines have become more powerful and more adaptable to a wider variety of ground conditions; so much so that tunnels are now being constructed in ground conditions and in the vicinity of third party impacts that would have been considered beyond the state of the art just ten years ago (see Image 1 for an example—a mixed ground Crossover TBM used successfully at Mexico City's Túnel Emisor Poniente II).

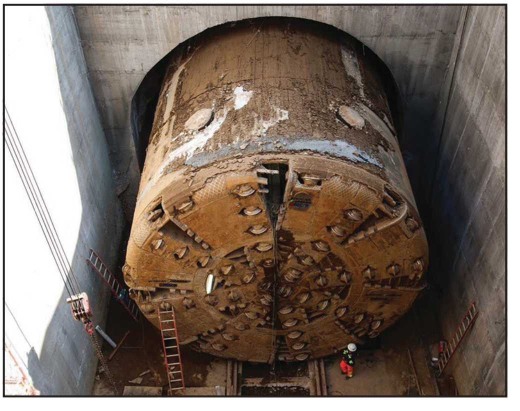

Figure 1. Modern TBMs like this one used at the TEP II in Mexico City are capable of successfully excavating in soft ground and hard rock

All of the above is highly advantageous for the tunneling industry but it has also placed a much higher level of risk on the performance characteristics of the tunneling machines, on the contractors operating those TBMs, and on the manufacturers of those machines. Most of the risks for a tunneling project are associated with creating the space inside of which the finished facility will be constructed. In order to create that space the tunnel contractor must make many decisions about the best way to *excavate the ground*, the best way to *control the ground* at the face of excavation, and the preferred method for *supporting the ground* around the tunnel in a manner that is safe for the workers and stable with respect to all of the overlying and adjacent existing structures. If it is proposed to use some form of TBM in order to build the tunnel, then the TBM becomes central to all three of the above activities and becomes an integral part of managing the risks associated with those activities.

The primary objective of this paper is to discuss how the TBM manufacturer can and should work together with a tunneling contractor in order to minimize and then to manage (i.e., control) many of the risks associated with a tunneling project. In

Figure 2. The McNally roof support system utilizes steel slats extruded from pockets in a TBM's roof shield

general, and as all members of the tunneling fraternity are well aware, there are lots of risks associated with every tunneling project which need to be identified, allocated, and managed as a result of the various contracts between the Project Owner and the Designer, between the Project Owner and the Prime Contractor, and between the Prime Contractor and various subcontractors and equipment suppliers; including the TBM manufacturer. As with any contract, the responsibilities of the various parties need to be clearly stated and the basic framework of the contract should create a fair and equitable working relationship between the parties. This becomes a most interesting challenge for the TBM manufacturer since he is providing an extremely complicated and expensive piece of equipment that is central to project success; not only as a result of its mechanical performance and durability but also as a result of how it is *operated* by the Contractor. Hence, many things must go *right* in order for the TBM to contribute in a positive manner to the successful outcome of a tunneling project. In order to address the topic of risk as related to the TBM manufacturer this paper is divided into the following sections:

- TBM Performance Characteristics
- The TBM Contract Document
- Managing TBM Risks During Construction
- Summary and Conclusion

Following the above, this paper will also discuss some of the next steps associated with industry change foreseen by the authors.

TBM PERFORMANCE CHARACTERISTICS

As stated above the TBM contributes to project success in two very important ways:

1. Its mechanical performance and durability, and
2. Its ability to help control potentially adverse ground reactions.

For instance, for a rock tunnel the TBM must be able to dependably excavate the rock and to allow for all aspects of equipment maintenance in a predictable manner. Prior to bid, the TBM manufacturer provides the bidding contractor with operating criteria and expected TBM technical capabilities based upon geological information provided by the owner's consultants and the project TBM specification; this is then incorporated by the contractor into his bid. In general, rock tunnels do not have negative impacts on adjacent existing structures and in most situations, it is relatively easy to install adequate support in the tunnel utilizing equipment provided as part of the TBM unless the tunnel is in highly faulted ground, stressed ground, or mixed-face conditions (see Figure 2—an example of an easy-to-install ground support system for open-type TBMs known as the McNally roof support system).

However, operating criteria for EPBs, SPBs and Mixed Soil and Rock TBMs are far more complicated than rock TBMs because of the enormous variations in different types of soil. Soil behaviors can vary from firm ground needing little face control and/or support to flowing ground and high water pressure, which can create huge problems both for the machine itself and for adjacent structures. In addition, soil TBMs have a more difficult interface between the machine's inherent performance characteristics and how that machine is *operated* by the Contractor, particularly in highly variable subsurface deposits. Hence, a perfectly good TBM can be operated in a manner that causes problems for the equipment, problems for tunnel production, and problems for third parties.

The bottom line for all of the above is the preparation of a listing of required TBM capabilities. These capabilities should be mutually agreed upon both by the tunnel contractor and by the TBM supplier, and must also meet the consultant's criteria. The specifications must be completed prior to commencement of TBM manufacturing. Listed below is a general example of TBM requirements:

- Proper Size with Sufficient Drive Power
- Cutterhead Design and Excavating Tools
- TBM Shield and Working Chamber
- Ground Conditioning at the Face for Either Rock or Soil or Both
- Thrust Capacity and Steering Control
- Spoil Removal within the TBM and along the Tunnel
- Spoil Weight/Volume Verification
- Bearing Seals and Tail Seals
- Shield Gap and Annulus Injection System
- Facilities for Ground Support Installation
- Guidance System and Alignment Control
- Data Loggers and TBM Performance Monitoring

All of the above TBM technical capabilities are incorporated into a technical proposal prepared by The TBM supplier with extensive input from the tunnel contractor. In essence, this single document represents one of the most important parts of the planning effort for a successful tunneling project built with a TBM. When the TBM disappears through the shaft wall or portal face the assumption is that it is equipped with all of the technical capabilities needed to make it to the exit end of the tunnel. If that is not the case, then significant project delays are in the offing, either as a result of reduced rates of advance or because of TBM modifications needed while in the tunnel. A TBM can be modified while underground using a suite of options known as Difficult Ground Solutions (DGS), to be discussed later in the paper. However, these features are much more effective at reducing risk if they are included on the TBM before it is launched.

THE TBM CONTRACT DOCUMENT

In order to accomplish the performance capabilities listed above the TBM supplier must design and manufacture a TBM for each specific application. With respect to the TBM's mechanical performance and durability the TBM is expected to operate "effectively" under very harsh conditions and for the duration of construction and it goes without saying that the different parties associated with a project will have radically different concepts about the meaning and the expectations associated with the word "effectively." One of the most common causes of claims, disputes, and lawsuits is the occurrence of "unfulfilled expectations" by one or more of the parties in a contractual relationship. Hence, and as a result, one of the most important goals of contract preparation is to forthrightly and unambiguously control project *expectations* in the contract wording. It is also important as a part of contract preparation to establish the fair and equitable distribution of project risks among the contracting parties.

The two most important sources of the risks associated with TBM performance are how well the TBM interacts with "anticipated" ground conditions both with respect to tunneling productivity and with respect to possible negative impacts on overlying and adjacent existing structures. Hence, the contract document for the TBM supplier should have well-developed descriptions for both anticipated ground conditions and for major third party interactions as provided in the project-specific Geotechnical Data and Baseline Reports. In addition to the geotechnical and third party considerations there are numerous other items that should be established in the TBM contract document and given below is an annotated listing of some of those items:

- **Warranty**—Clearly the TBM should be expected to perform reliably and at progress rates provided by the TBM supplier, and a warranty paragraph to that effect should be included.
- **Limitation of Liability**—However, a warranty only applies to the TBM itself and not to liquidated or consequential damages, force majeure, duty to defend, or project delay. Hence, the TBM supply contract should contain a valid Limitation of Liability paragraph addressing those topics.
- **Differing Site Conditions**—The TBM contract should also provide access for the TBM supplier to the legitimate application of the DSC clause. If the ground is found to be materially different as indicated by the prime agreement, then the TBM may need to be modified after the drive has begun.

- **Dispute Review Board**—The TBM supplier should also have access to some form of dispute resolution as part of its contract.
- **Safety**—The TBM Supplier is not responsible for on-site safety unless the TBM itself contributes to a problem. Hence, whenever TBM supplier personnel are on-site they are there as "guests" under the Prime Contractor's safety plan as explained in OSHA regulations.
- **Flowdown Requirements**—The TBM supplier must be extremely careful about flowdown requirements from the prime agreement which may or may not be applicable to the TBM supply contract. In general, the TBM supplier should not accept a blanket statement that all obligations contained in the Prime Contract apply to the TBM supplier. Some examples of problematic flowdown requirements are Indemnification, Duty to Defend, Liquidated Damages, Hazardous Materials, Default and/or Termination Provisions, and Waiver of Rights.
- **Standard of Care**—The TBM supply function also involves a large component of engineering services and the TBM supplier should only be deemed to be liable for those services if they were performed "negligently." This "Standard of Care" is also closely related to the TBM suppliers' proposed Scope of Services as explained below.

Probably the most important part of the TBM supplier's agreement is a detailed description of his Scope of Services. Almost no matter what is written in the body of the contract the TBM supplier can control its potential liabilities by explaining in detail the services it intends to provide and, equally importantly, those services and/or project activities for which it is not responsible. For instance, the TBM as supplied will have certain performance capabilities but that does not mean that the TBM will be operated and/or maintained in a proper manner in the field. Improper TBM operation and maintenance can be a significant risk for a tunneling project and the TBM supplier must limit its liability for inappropriate TBM operation. The TBM manufacturer cannot be held responsible for the damage caused by an unqualified TBM operator or by unqualified modifications to the TBM (see Figure 3—an example of a modification installed by a contractor that may have contributed to significant equipment downtime).

MANAGING TBM RISKS DURING CONSTRUCTION

The risk profile for a tunneling project can be divided into four steps:

1. Risk Identification
2. Risk Avoidance and/or Minimization
3. Risk Allocation
4. Risk Management.

All activities associated with Risk Identification, Risk Avoidance, and Risk Mitigation take place during the planning and design stages of a project wherein the Owner and his Design Consultants attempt to formulate a risk profile that is described in the risk literature As Low as Reasonably Practical (see SME Guidelines for Risk Management, 2015). This is an extremely important responsibility on the part of the Owner and its Designers as it represents a sincere desire by those parties to provide a contract document for bidding where the risks for *all* parties to the contract have been minimized as much as possible. At that point, the Owner's remaining responsibility is to *allocate* any remaining risks between itself and the Prime Contractor in a fair and equitable manner in the contract document for construction. After award, this process continues as the Prime Contractor continues to allocate its risks to various subcontractors and equipment suppliers. Hence, and for this paper, the question remains how much tunneling risk can be fairly and equitably allocated by the Prime Contractor to the TBM supplier.

For instance, and as discussed above, the TBM cannot be expected to perform in a ground condition that is known to be materially different as indicated

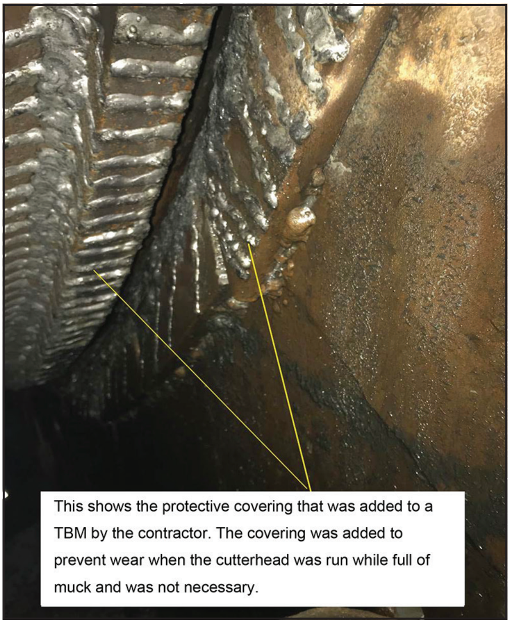

Figure 3. An example of contractor-added machine modifications that were unnecessary

by the contract document. Other examples of dramatic differences between TBM performance characteristics and operational requirements would be as follows:

- **Gassy Ground**—The TBM can be equipped with gas monitors but the Prime Contractor is still responsible for ventilation issues and evacuation procedures.
- **Over-Excavation**—The TBM can be equipped with monitors that show how much spoil is being removed from the tunnel but that doesn't necessarily stop the TBM operator from over-excavating. Presently, there is no single monitoring system available that can accurately measure the volume and density of material being removed from the tunnel. Therefore several monitoring systems should be utilized on each project (Robinson et al, 2012).
- **Guidance**—The TBM will be equipped with a laser guidance system but survey errors may still cause the machine to go off of alignment.
- **TBM Maintenance**—Poor TBM maintenance by the Prime Contractor may cause TBM utilization to suffer or premature failure of components to occur through no fault of the TBM supplier.
- **Operator Training**—The TBM supplier can offer training but the Operator qualifications and capabilities are the responsibility of the Contractor. Improper operation of equipment is one of the leading causes of tunneling delays.

The complete list of TBM performance capabilities versus TBM operational responsibilities is long and, as described above, can result in "unfulfilled expectations" for a tunneling project. The main issue raised by all of the above is: How can we write a good contract that clearly defines the design of the machine and the TBM supplier's responsibility, as well as the contractor's responsibility and scope of machine operation?

NEXT STEPS TOWARDS INDUSTRY CHANGE

Looking at TBM Procurement Differently

There must be a more objective way for owners and contractors to view risk, other than looking for the lowest equipment price and highest willingness to accept risk from a TBM supplier. In fact, a correctly designed TBM is the key to a project's success, and correct machine design, even with increased initial cost, is part of that formula to success. Field results have shown, time and again, that a TBM built with "risk insurance"-type features (such as probe drills, shield lubrication, etc.) can have a huge impact on a project's success in terms of schedule, cost, and safety. It is far better to build features into the machine from the start as part of a comprehensive risk management strategy, than to add them in the tunnel after an unforeseen event has occurred or the machine has become stuck.

Even when risks are considered low, it is still better to equip the machine from the outset with the tools needed to get through unforeseen conditions. These tools have been tested in the field and can mean the difference between project success and failure. Robbins currently is equipping several shielded hard rock TBMs with Difficult Ground Solutions (DGS)—a suite of options that can prevent a machine from becoming stuck and can enhance visualization of the ground around the TBM (Harding, 2017). For example, two-speed gearboxes allow a rock machine to shift into a high torque, low RPM mode to get through fault zones and collapsing ground without becoming stuck (see Figure 4—an example two-speed gearbox torque-speed curve).

Shield enhancements such as external shield lubrication can further keep a machine from becoming stuck. Radial ports in the machine shield can be used to pump Bentonite between the machine shield and tunnel walls to reduce friction (see Figure 5).

Emergency thrust systems are another addition that can be deployed when ground convergence occurs. Additional thrust jacks between the normal thrust cylinders can supply added thrust in a short stroke to break loose a stuck shield (see Figure 6).

Remedying Contract Structures to Reduce Risk and Cost

As mentioned throughout this paper, a contract structure that clearly defines the responsibility of the supplier and the responsibility of the contractor while allocating risk fairly is what is needed. Contractors must take responsibility to allocate the appropriate amount of risk given the limited capabilities of a given machine.

Part of more accurate risk estimation lies in the industry's ability to find and utilize consultants who are up-to-speed on the latest in TBM technology and mixed ground capabilities, and can therefore accurately specify the technical capabilities required of a given machine.

Another aspect of inexperience and improper risk allocation is the extreme specifications that are being created for many current projects. These specifications vastly overestimate the given risks of a project (e.g., if test results show 200 MPa rock, they will want to have a solution capable of excavating 300 MPa. If tests show 100 l/sec water inflows they will want a solution capable of handling 200 l/sec). These types of specifications increases

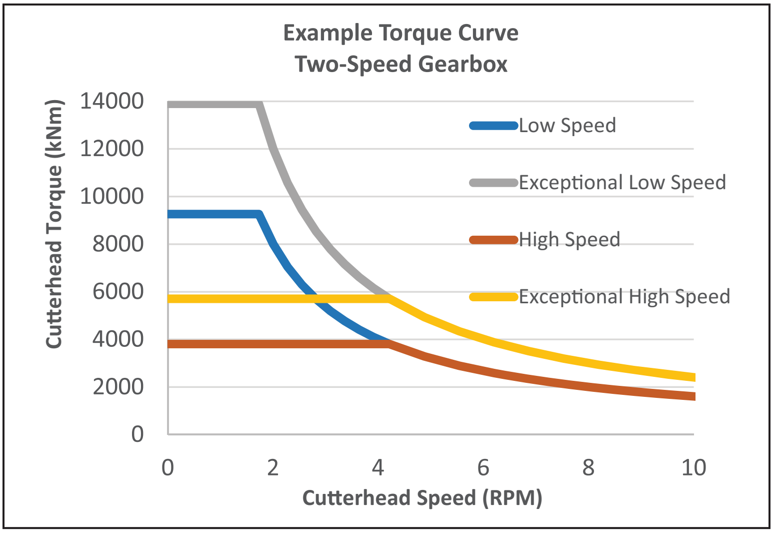

Figure 4. Example torque-speed curve for a TBM with two-speed gearboxes

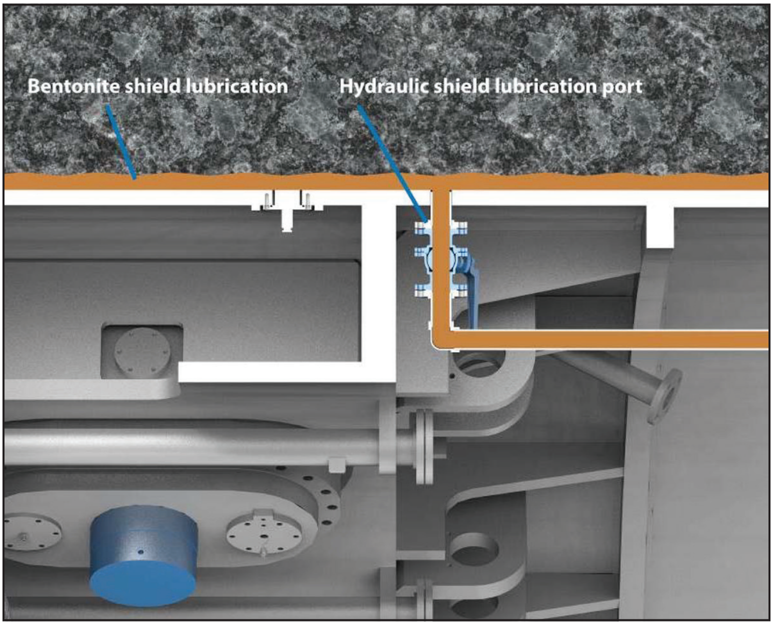

Figure 5. External shield lubrication system

the complexity of a TBM needlessly, and thereby increase the cost of the end product to the owner.

Risk-based cost and schedule estimation is being used on more projects, and will be an important part of the process moving forward (Sander et al, 2017). But even with these tools and the industry guidelines available—such as those produced by the UCA of SME (O'Carroll & Goodfellow, 2017)—an increase in industry knowledge of those tools is needed. If these tools are not used, the unequal allocation of risk will continue.

Operating the TBM Differently

When an adequate GBR is lacking and/or when risks can't be properly quantified, a push for continuous

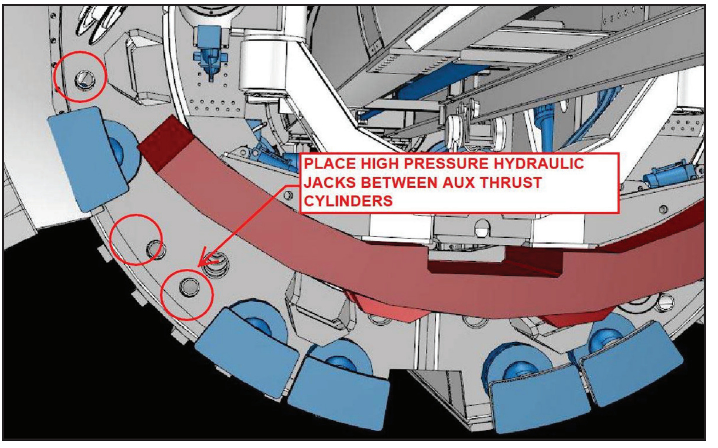

Figure 6. Possible locations for additional thrust jacks

probe drilling should be made by all parties involved. Writing continuous probe drilling into the contract can and has effectively reduced risk—but we need more buy-in from the industry. Through continuous probing, crews can generate an in-tunnel GBR concurrent with advance. This GBR could be used to analyze trends and predict upcoming transition zones. The requirement for an in-tunnel GBR would effectively force contractors to take the time to analyze what is ahead of them—a small price to pay when a big feature is detected in time to save the tunneling operation.

In addition, the TBM supplier should have more ways to address improper operation of the TBM by the contractor. The supplier should have access to the Dispute Review Board as readily as the contractor so that justification of a lawsuit, or lack thereof, can be determined by all parties involved.

SUMMARY AND CONCLUSION

The tunneling industry has seen enormous advancements in the performance capabilities of all forms of Tunnel Boring Machines (soil, rock, mixed rock/soil and small diameter) to the point that tunnel success has become intimately related to those capabilities. As an additional result of those advancements tunnel designers and tunnel contractors are continuously pushing the envelope for the size, length, depth, and alignments of tunnels in difficult ground and in the immediate vicinity of sensitive, existing third party structures. Hence, tunnel designers and contractors are becoming highly reliant on the knowledge and experience of TBM suppliers to rise to the challenge of those increasingly challenging projects; however, there are limits. The TBM supplier's financial opportunity for providing the equipment cannot be allowed to outstrip its responsibilities for project risks. Machine capabilities are still limited and cannot be expected to serve as the primary excuse for unrealized project expectations. In the final analysis all parties involved with the successful completion of a tunneling project including project Owners, Designers, Prime Contractors, Subcontractors, Suppliers and Insurance Companies must accept their fair share of risk commensurate with the benefits associated with their contribution to the finished facility. From that perspective, the TBM supplier is not high on the list of project beneficiaries and, therefore, cannot be expected to assume unreasonable project liabilities relative to their role in the project. Hence, unreasonable attempts to transfer project risks to the TBM supplier must be controlled in no small measure so as to actually protect the integrity of the tunneling industry.

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