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A TRADITION OF INNOVATION

The Next Push For Machine Tunnelling

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A TRADITION OF INNOVATION
The Next Push For Machine Tunnelling

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>> In Brief

- Conditions are changing in the tunneling industry, with more difficult tunnels being proposed.

- In decades past, the tunnel contractors and machine builders accepted a higher level of risk than the industry is used to today. Within this climate, everything from disc cutters to Double Shield tunneling was developed.

- Contractors, manufacturers and owners thrive by taking risks because of the inventiveness and problem-solving capacity that risky projects require.

- The proper allocation of risk will allow the development of new and even better machines to tackle today's tough tunnels.

- Risky projects will always be a part of our industry, so all parties involved need to embrace risk.

- It should be the duty of those of us that have been in the tunneling industry for decades, to pass on the culture of innovation that we embraced.

1 >> Introduction

As a relatively mature industry, the world of machine tunneling is more conservative than it once was. While there is a place for standardized machinery and design elements on many projects, some projects require ingenuity and a progressive approach. Challenging and risky projects will always be a part of our industry and stepping out of the comfort zone of standardized technology on these tunnels is part of achieving success. The effect of industry-wide conservatism is often the outcome of an effort to drive down risk, whether that is through contractual practices, industry regulations, or standardized technologies. However, all parties from contractor to equipment supplier to the project owner can be successful with challenging projects so long as the risks have been properly and fairly allocated.

The industry has already made large advances from its infancy in the 1950s and 1960s. Jobs that were once considered high risk are now standard—a trend that is particularly pronounced in mixed and soft ground. Today's Earth Pressure Balance (EPB) and Slurry Tunneling Machines provide the opportunity for machine tunneling in more complex geology than ever before, and as the conditions get more complex there will be more opportunities for taking risks and using new technology. The potential of our industry is great, and we have the chance to build tunnels now that were never possible in the past. This possibility is what is most exciting.

2 >> The Mechanized Tunneling Industry In Its Infancy: High Risk, Big Reward

It should be pointed out that the idea of tunneling machines creating tunnels is a concept at least 167 years old that has intrigued engineers, planners, and financiers. Throughout history it has seen moments of brilliance and failure with a rebirth every 30 to 40 years, sometimes occurring more frequently. This fact was clearly illustrated by the Australian author Barbara Stack in her first historical tome, "Handbook of Mining and Tunneling Machinery" (Stack, 1982). In spite of vast sums having been spent in almost 20 decades, history had to wait for the first truly economic success of machine tunneling

The era of modern tunneling machines began in 1952, with an initial design used at South Dakota's Oahe Dam, developed by James S. Robbins. That first machine utilized a dual counter-rotating cutterhead fitted with rows of drag bits and dumbbell-shaped disc cutters to mine through weak shale. After achieving good advance rates, that machine and three subsequent tunneling machines were used for six power tunnels and seven diversion tunnels at the Oahe Dam site.

As tunneling machines were in the early stages of development, Jim Robbins would design and build a new piece of machinery to fit particular needs. He would then convince an owner or a successful contractor to fund the building and testing of the machine. Often there would be problems as the design was tested and improved. These improvements usually took place in the tunnel during construction. At that point, Robbins and the contractor would get together and work out a solution. This was sometimes a collaborative process. At other times, the contractor would decide to withdraw the machine from the tunnel and carry on tunneling with drill and blast methods.

Jim Robbins' work was terminated by his untimely death in 1958, having built seven tunneling machines. No other tunnel machine designer or builder had yet emerged to that date, and would not emerge on the scene until about 1960. However, his contribution initiated an era of mechanical tunneling and an industry that has grown to the present day. Needless to say, the industry has changed greatly since those early days, but it is worthwhile to take a look at some of the concepts that came out of that period.

2.1 POATINA HYDRO TUNNEL: A REVOLUTION FOR GRIPPERS AND DISC CUTTERS

One of the earliest such examples occurred in Tasmania in 1961, where the Great Lake Power Development was underway—a massive scheme being developed for the Hydroelectric Commission of Tasmania. The Robbins Company was contracted to supply a 4.9 m diameter hard rock tunneling machine for the Poatina Tunnel, a 6.9 km headrace tunnel in mudstone and sandstone up to 118 MPa compressive strength. The machine was built in Seattle, Washington, USA. The assembly, completed in six months, included a number of unique features for the harder rock conditions including the floating gripper system and new disc cutter designs.

2.1.1 Floating grippers

Earlier tunnel machine designs at the Oahe Dam in 1952 and other tunnel sites utilized the mass of the machine to counteract torque during boring. These early machines sat on wide rails, and the back-up system was built right onto the machine. The machines did not have grippers, and because of this the rear feet tended to lift up and to the right, making them somewhat unstable. In place of grippers, hydraulic jacks shoved off of steel ribs placed at the front of the machine—a method that also meant steel ribs had to be placed regardless of the ground conditions (Figure 1).

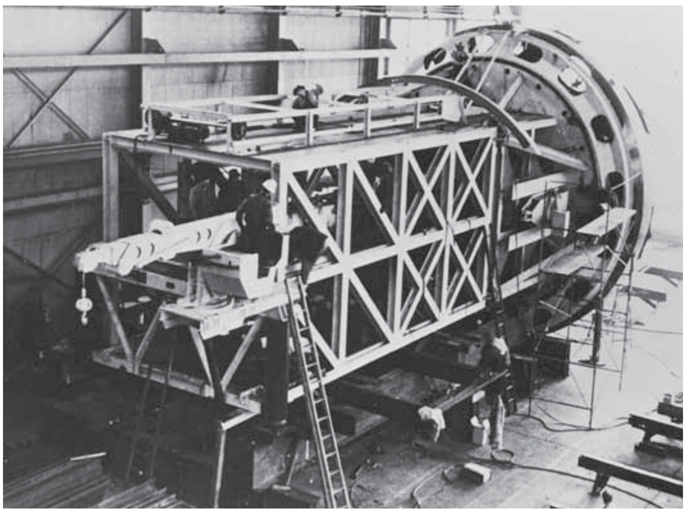

Figure 1. An early machine without grippers

2 >> The Mechanized Tunneling Industry In Its Infancy: High Risk, Big Reward

Subsequent Robbins machines in smaller diameters used a type of fixed gripper, but this greatly limited steering. At an Ontario, Canada project in 1956, the Humber River Sewer Tunnel was excavated using a tunneling machine in hard crystalline limestone using a full dressing of disc cutters and fixed-type grippers. The grippers would grip against the rock, but once it was in this position the machine had to travel straight forward. If the machine operator were to try to steer, the grippers would break free of the walls and the body of the machine would rotate. Because of this, the operators at the Humber River sewer tunnel had to be very cautious with steering of the machine.

For the Poatina, Tasmania Tunnel, Robbins wanted a design that would guarantee continuous steering abilities. The machine was to bore in hard sandstone, so the first-ever articulated (floating) gripper system was designed for these conditions. The patented design was a success, allowing for continuous steering during a push when the grippers were engaged against the tunnel walls. Other design changes such as permanently sealed, large diameter main bearings were developed to improve bearing life and to keep oil in and dirt out of the mechanisms.

2.1.2 New cutter concepts

In order to excavate in harder rock, a new disc cutter design was also developed for Poatina. The first metal-to-metal cutter seals were developed consisting of a pair of metal seal surfaces and "o"-ring-like elastomeric toric rings. This greatly improved bearing life in hard rock. The concept developed and successfully used on that tunnel is still in use today.

2.1.3. Project excavation

The owner, which performed its own construction services, went with the relatively radical design in part because of its experience with underground construction and a high confidence in the engineering capability of its staff. Before acceptance of the machine, the owner built a scale model of the machine cutterhead with the proposed disc cutter design. After testing the model, the owner determined that it could cut rock faster than drill and blast, and accepted the new designs. The owner also felt comfortable with the new concepts because it had a large manufacturing facility that could be used for redesign and refurbishment should there be a problem with the new features.

The Poatina tunneling machine began excavation in March 1961, in an industry climate where tunneling machines were considered experimental and Drill & Blast (D&B) was the standard. World records were very important, particularly in Australia because that country held the world record for tunneling at that time. Their record using D&B in the Snowy Mountains topped out at about 137 m per week—a record that was nearly doubled by the Poatina machine. During a six-day work week the machine advanced 229 m, and achieved a best shift advance of 18.2 m, proving that tunneling machines could indeed excavate faster than drill and blast. The success at Poatina set the stage for further tunnel machine use in hydroelectric tunnels worldwide and cemented the floating gripper as a successful design concept (Figures 2-3).

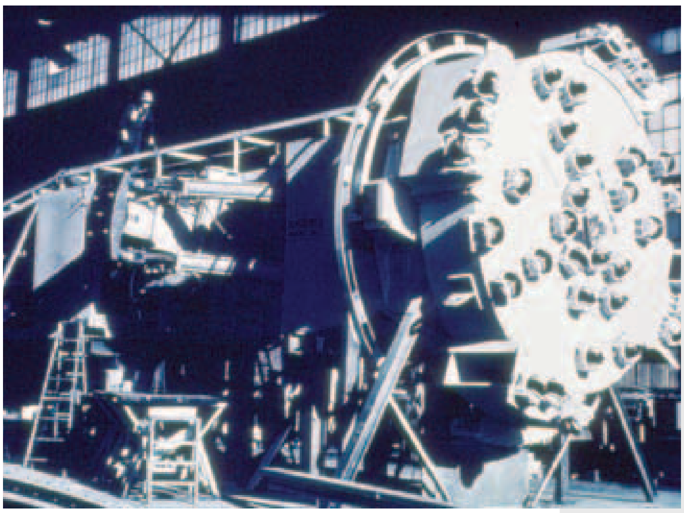

Figure 2. The Poatina Hydro Tunneling Machine, circa 1960

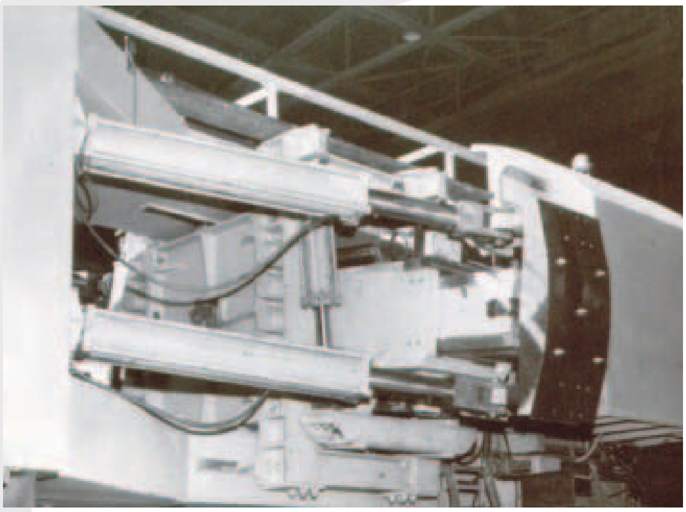

Figure 3. Close-up of the first Floating Grippers

2.2 DOUBLE SHIELD TUNNELING MACHINES

A further development in machine tunneling in the 1970s would forever change excavation in fractured ground. In 1972, a water transfer and hydro project in Calabria, Italy resulted in a breakthrough in tunnel machine technology. The Orichella and Timpagrande Tunnels were to be excavated at 4.3 m in diameter in fractured granite on a tight construction schedule. Robbins designed a concept and worked with Carlo Grandori of SELI to provide a machine that would allow the placement of segments during boring. The concept would provide faster excavation since boring and lining would not have to be a sequential process (Figure 4).

The Robbins concept ultimately became the first Double Shield tunneling machine, now a successful machine type used on projects in fractured ground around the world by several other manufacturers.

Figure 4. The first Double Shield Tunneling Machine, for Italy's Orichella project

2.3 DESIGNS THAT REMAINED IN THE TEST PHASE

2.3.1 Water jet-assisted cutters

Not all concepts were so successful, of course. Concepts such as water jet-assisted disc cutters utilized high pressure jets operating at over 60,000 psi (4,000 bar) to achieve faster advance rates. A Robbins tunneling machine was built with discs and jets and used in a test tunnel in granodiorite rock. The machine with conventional cutters alone was able to penetrate at a faster rate than the jet-assisted cutters, rendering the water jets unnecessary (Figures 5-6).

Figure 5. Test TBM for water jet-assisted cutters

Figure 6. Excavation face

2.3.2 A triple shield design

In the 1990s a unique machine design was developed for the Superconducting Supercollider particle accelerator tunnel in Texas, USA.The 4.82 m diameter machine was designed to bore, advance, and install pre-cast segments simultaneously using a triple shield. Automated gripper sets could be used, with a set mid-shield that could be used for one stroke and a rear shield set to continue forward motion (Stack, 2010). The machine could also operate more conventionally as a standard Double Shield in difficult ground, or in very difficult ground as a Single Shield TBM pushing off of segments (Figures 7-8).

In practice, however, the triple shield design was not reliable enough to warrant its extensive use in the tunnel. The extensometers used on the hydraulic cylinders to automate the gripping and propulsion process were prone to repeated breakage. Although technology did exist at the time for internal extensometers, the modifications necessary to utilize the triple shield features on this project would have taken too much time. As a result, the machine was used as a Double Shield and the continuous advancing feature has not been used since, although its potential could certainly be relevant for current and future projects.

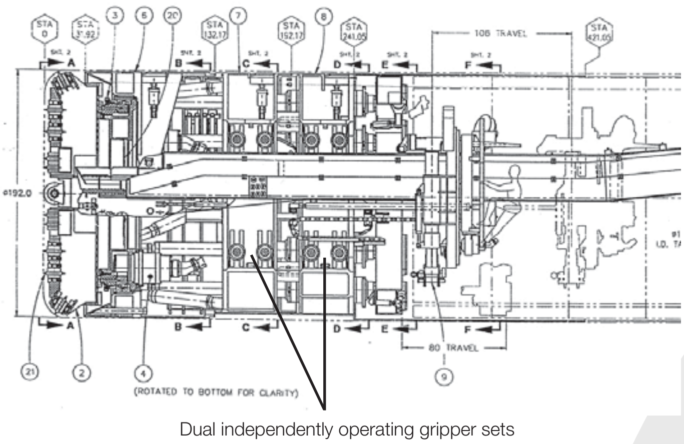

Figure 7. The Triple Shield Tunneling Machine Design

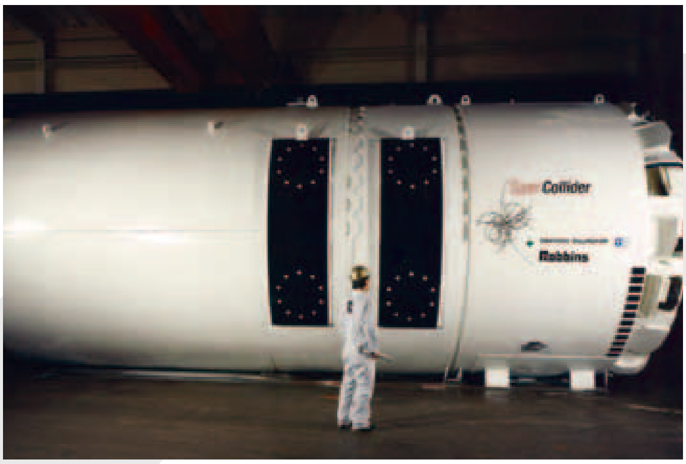

Figure 8. Side View of the Triple Shield Tunneling Machine

3 >> Early Pressurized Tunneling: The Paris RER Metro

An example of successful innovation in mixed ground tunneling occurred at the Paris RER Metro in 1964. This project utilized a tunneling machine designed and built by The Robbins Company with conceptual input from the contractor Etablissements Billard. The resulting machine was the precursor to all modern EPB and Slurry shield machines. The job required excavation of a 2.9 km long tunnel in mixed ground and bedded layers of broken rock below the water table. This Paris machine utilized a pressure bulkhead, which consisted of a steel plate structure located in a zone behind the rotating cutterhead that completely sealed the forward portion of the machine from the aft portion. The forward zone was kept pressurized with compressed air while the rear zone was open to atmospheric pressure. Rotary buckets in the pressurized zone transferred the muck into a 'conveyor tube' that remained pressurized and discharged muck through a pair of alternating hoppers in the free air zone.

Multiple challenges during tunneling required adaptations. During excavation, there was a large variation in water pressure between the top and bottom of the tunneling face, while the pressure of the compressed air was constant. This required over-pressurization of the chamber, which allowed compressed air to escape out of the top of the cutterhead zone. The machine was excavating through thin coal seams, and at one point the high pressure of the compressed air caused ignition. While not explosive, the face was burning, so the contractor had to lower the air pressure to allow water to enter the face and put out the fire. In order to keep the problem from recurring, the elevation of the tunnel was raised upward in a gradual 15 m incline to reduce the required air pressure. This carried risk in itself because the contractor was tunneling below the Seine River. In spite of these difficulties, the job was successfully completed (Figures 9-10).

After the project, J.V. Bartlett (a senior partner in the British engineering firm of Mott, Hay, and Anderson) recognized the problems with compressed air, and developed the design concept of a slurry tunneling machine. He replaced the compressed air with thixotropic mud, which was used to move the cut rock and soil out of the face and into the free air zone. He patented this idea, which was further refined by German and Japanese companies in the years that followed.

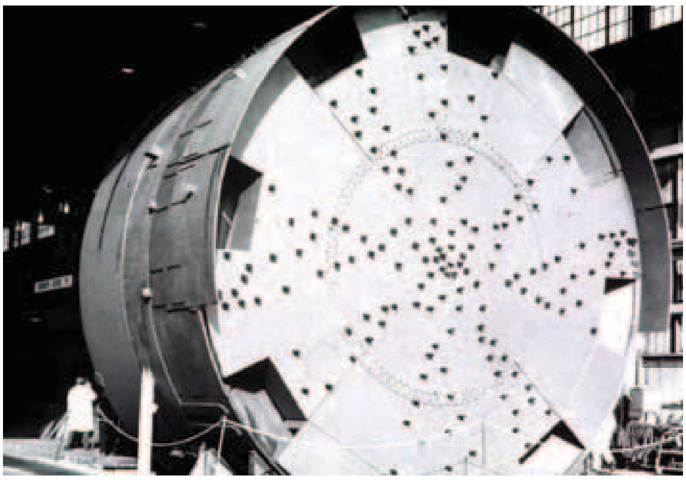

Figure 9. Compressed air TBM at the Paris RER Metro

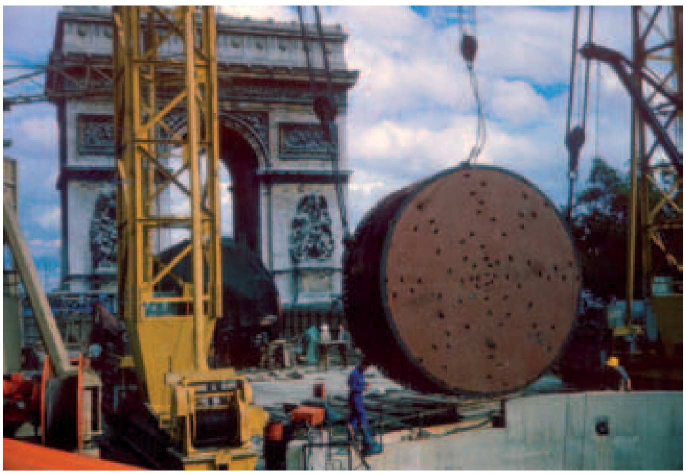

Figure 10. Lowering the cutterhead (Arc de Triomphe in background)

4 >> A More Modern Case Of Innovation: The Channel Tunnel

The Channel Tunnel, excavated below the English Channel between 1987 and 1990, is one of the most famous examples of successful innovation in tunneling. The project was the culmination of over 100 years of starts and stops in attempts to build a tunnel below the English Channel. The difficult 39 km long tunnel system included three tunnels excavated eastward from Britain and westward from France.

4.1 The french channel tunnel machines

The first 2 km of tunnels from the French side included faulted, fractured rock filled with seawater under pressures up to 10 bars. Hybrid articulated shield machines were developed for this project that could operate in both open mode and under pressure—something that had not been previously tried.

The designs for the French side featured the first ever telescoping cutterhead inside a pressure bulkhead machine shield. The machines bored rock flooded with seawater, which was removed using a screw conveyor operating in the high pressure water zone. The screw emptied into a double-acting muck lock, which acted like a large muck pump. From that point muck was discharged to a second screw at atmospheric pressure, and then into muck cars (Figure 11).

The hybrid concept was not the only new design to be introduced. The machines utilized PLC systems to monitor and control various processes. Dual-armed segment erectors placed and bolted the sealed segments faster to achieve a near-continuous flow of progress (Figure 12).

Figure 11. Channel Tunnel Hybrid articulated shield machine, French Side

Figure 12. Setting Segments and Back-fill Grouting in the Channel Tunnel

4 >> A More Modern Case Of Innovation: The Channel Tunnel

4.2 THE BRITISH CHANNEL TUNNEL MACHINES

The three tunnels progressing eastward from the British side were somewhat more conventional Double Shield machines due to more favorable geology, but they also included some unique, innovative features. The British machines were built with sealing systems to seal the tunnel and machine against very high water pressure in the event the machine encountered an open bore hole connected to the sea bed or an unexpected open fault (Figure 13).

4.3 PROJECT COMPLETION

The designs were highly successful—by the time of completion on December 1, 1990, the machines had excavated record months of up to 1,232 m. Though all the machines started slowly, they completed the tunnels close to the original schedule. The production schedules anticipated progress rates of 300 m a month, whereas in fact there were months when all six of the machines building the three tunnels achieved over 1 km (Figure 14).

4.4 CHANNEL TUNNEL ECONOMICS

While the Channel Tunnel is a great example of the success of new design concepts, it was not as successful in terms of financial results. The financial risk of the project was great compared with the cost to build the three tunnels, and ultimately project costs were not fully recouped. Surface transport across the English Channel via ferry had much lower operating costs, and the underground transportation system could not compete.

This scenario is closely tied with both local and worldwide economic conditions—an aspect of risk that must be considered on large tunnel projects.

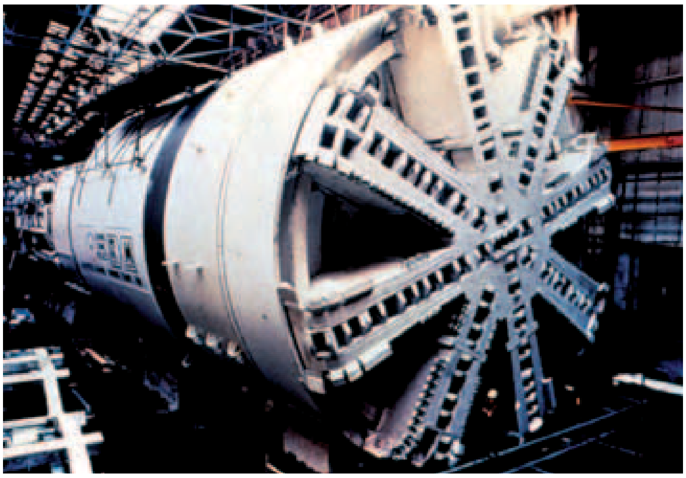

Figure 13. Channel Tunnel machine, British side

Figure 14. Workers celebrate the completion of the Channel Tunnel, French side

5 >> How It Changed: The Evolving Role Of Risk

When equipment manufacturers were starting out and in the decades following, a large amount of investment was typically spent on new design work. This was especially true of hard rock machine tunneling, but also happened in mixed ground through the 1980s and 1990s. As the economic situation tightened up worldwide, the industry was forced to make more incremental improvements.

ECONOMIC RISK

Risk evaluation has to do with the economic picture at a given time. If the economic picture is deteriorating, then risk is heightened. Collaboration amongst all the parties involved is need to reduce risk and clarify responsibility. In the period from the 1980s to the 2000s, new contract models were also evolving, such as Design-Bid-Build, and Build-Own-Operate (ITA Working Group, 1996). More recently, an owner may not only need to build a tunnel, but also find a financing organization to own and operate it after the construction is completed. New contract models have been recommended as a solution to resolve growing conflicts between contractors and owners. Frequently, owners attempt to protect the tax-paying public from overruns of cost and schedule. However, new contract models may result in the size of projects increasing, with risks to all parties increasing.

In recent years these new contract structures have spurred many discussions by groups like the ITA, national tunneling groups, industry trade magazines and academic circles. The question is about risk sharing: How to achieve a proper balance of risk between the owner , contractor, and the manufacturer? How should a contract properly allocate risk among all of the parties? The risk environment has cornered contractors into doing more standard work, which in turn leads to more conservative tunnel designs. This then induces tunnel equipment manufacturers into offering more standard types of machines. Development work for new concepts has been reduced considerably, and there has been a lower percentage of new features on the market.

Not only is the contract specification a challenge, but also the magnitude of the project investment. Newer projects may be larger in scope, costing in the hundreds of millions or even billions in USD. This not only increases risk, but creates different kinds of risk as national governments, politicians, and even the public stakeholders become involved. Political risk has become an ever increasing factor.

6 >> The Current Climate Of Risk And State Of Innovation In The Industry

Today, as the industry of machine tunneling has matured, owners and contractors don't feel as dependent on manufacturers to solve problems. There is more competition among the manufacturers and stricter budgets from the contractors and owners. Contractor specifications often demand that machines start fast and operate at optimal speeds from near day 1.

Owners often require that contractors and manufacturers define who is responsible for each type of risk, and who will pay for what. The concept of risk now involves not only just the failure of a machine feature, but may also include all the consequences that stem from the problem (such as late project completion, and all of the economic consequences.)

In seeking some relief from this climate, experienced tunnel contractors have looked to emerging markets. In these markets, such as Southeast Asia, the Middle East, and Eurasia, contracting practices may provide an environment more welcoming to new design concepts.

MODERN INNOVATION AT WORK: THE SR 99 TUNNEL PROJECT

Despite all of the current challenges for creative development work in the industry, examples can still be found where innovation is encouraged—particularly where project conditions are exceedingly difficult or unprecedented. The SR 99 Viaduct Replacement Tunnel in Seattle, Washington, USA is an example of both modern-day risk sharing and innovative design work.

The project is one that almost did not happen due to political and economic pressures. It took a major earthquake in 2001 that damaged the Alaskan Way Viaduct and Seawall to move the high-stakes plan into motion. A tunnel was not initially even considered an option for the viaduct replacement—either a new viaduct or travel by surface streets was considered first. Public stakeholders turned the project around, citing traffic disruption and other factors and putting the tunnel option on the map. While two or more smaller tunnels would have been less risky, they were a more costly option, and ultimately the city and their team of consultants specified a large diameter tunnel, requiring what will be the world's largest ever tunnel boring machine at 17.6 m.

In spite of the world record size of the planned tunnel, the contractor rather than the owner took responsibility for the choice of the machine and the machine's features. The decision was weighted in terms of both technical merit and cost. The resulting machine incorporates unique concepts. Among them are such features as pressure compensating disc cutters that will allow the tunnel machine to excavate in water pressures above 4 bar. In the case of the SR 99 Tunnel, pressures up to 7 bar are anticipated.

PRESSURE COMPENSATED CUTTERS

Although pressure compensated cutters have been in use for years on shaft sinking machines and certain types of soft ground machines, the new concept improves upon earlier designs. The unique setup uses a pressure compensating retainer. This retainer is in contact with the lubricating oil inside the cutter and transmits external pressure to the inside to balance the forces on either side of the seal (Shanahan, 2013). Pressure-compensating pistons are also installed on the insides of the cutter shafts to offset the risk of plugging in an underwater environment (Figure 15).

While the machine at SR 99 has arrived in Seattle it has not yet launched as of this paper writing. The use of new concepts and the unprecedented project design show that the involvement of public stakeholders and a re-examination of the underground option can push progressive construction forward.

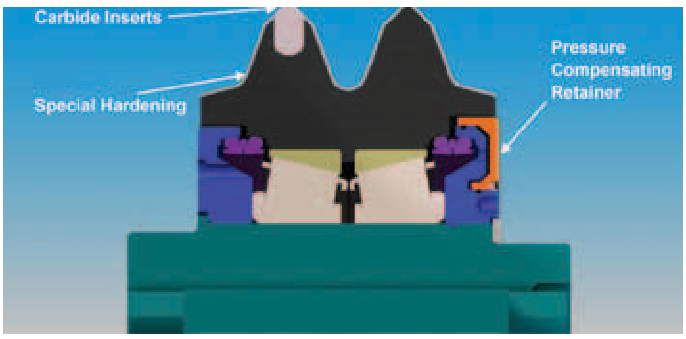

Figure 15. Pressure Compensated Carbide Insert Cutter

7 >> The Future Of Innovation In The Tunneling Industry

The reality of our tunneling industry today is that paradigm shifts and major new innovations are no longer occurring at a regular rate. Well-entrenched tunneling markets in the U.S. and Europe have developed among the world's most litigious societies, and this cultural framework makes the acceptance of new technologies more difficult. In emerging markets such as Southeast Asia, contracts are somewhat less rigid and the atmosphere is more amenable to innovation, with the result that today's tunneling machine innovations may be more likely to occur outside of the U.S. and Europe.

There are many opportunities in these emerging markets for new concepts that have not been tried before. For example, a large, 13 m diameter hybrid EPB/Single Shield machine is currently being developed for a project in Ankara, Turkey. This machine design features a number of unique concepts that streamline in-tunnel conversion between tunnel modes, making the switch from hard rock to pressurized EPB and back again a quicker process.

Other design concepts are testing machines in new circumstances. An 8.0 m hybrid EPB for the Grosvenor coal mine in Australia is being designed as explosion proof to bore through coal seams, and features a unique conveyor setup in order to bore the development tunnel at a 12.5 percent decline.

Unfortunately there is not a clear way forward to a more progressive European and U.S. tunneling industry. We have heard from our most experienced tunnel builders a demand: "Show me where it has been done before and I'll consider doing it." Yet on the contrary, if truly valuable new concepts are proposed, they can still become accepted over time. Such a proposal may be accepted as long as a back-up method is included that uses known technology in case the new feature requires too much time to solve problems in the tunnel.

A new ITA initiative known as ITAtech is pushing concepts forward through a manufacturer-centered group. The introduction of new concepts to industry is only supported with solid recommendations and a consensus among members of the group of manufacturers. This avoids placing more risk onto tunnel builders and project owners who would not otherwise accept an innovative concept. When the group promotes a new design it thinks is an advantage, it accepts revisions from its members because the gains will exceed any setbacks required for revision. The Robbins Company and other TBM manufacturers including Herrenknecht, Hitachi Zosen, and others are working to promote ideas and put them into the world knowledge base in this way (Smith, 2012).

The group has already shown promising signs, making the first steps towards introduction of a new type of Near-Zero Rebound Shotcrete, developed in Japan and in partnership with Robbins. The fiber mortar based shotcrete, used on a project outside of Japan, allows for application of reinforced shotcrete with minimal rebound in the L1 zone directly behind the cutterhead support.

ITAtech is also working towards standards for each machine type, so that bid specifications become clearer, including standards for Main Bearing capacity and life.

REVISITING DESIGN CONCEPTS AND PROPOSING NEW ONES

A number of design concepts that were proposed, built, and tried previously could be revisited today. The concept of the Triple Shield Machine is a stepping stone on the way to a Universal tunneler, which could operate in almost any ground condition and would ideally not require extensive conversion time in the tunnel between modes. Barriers to the Universal tunneler include cost and convertibility when geologic conditions change. Muck removal, which includes a ribbon or shaft type screw along with a temporarily connected belt conveyor, is being perfected today. Such machines need further development to lessen the requirements of time consuming and expensive interventions due to wear. Looking at these interrelated systems in a new way is required.

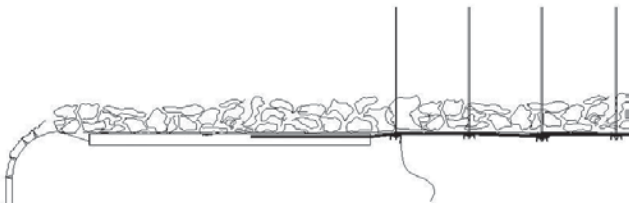

Figure 16a. McNally –system - slats installed

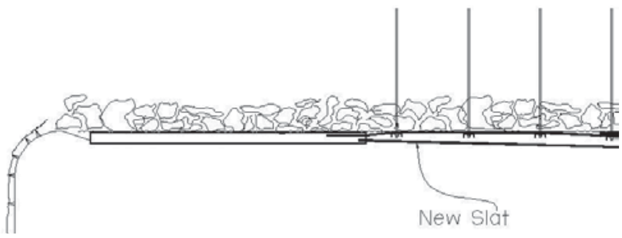

Figure 16b. McNally system – new roof slat inserted into pocket

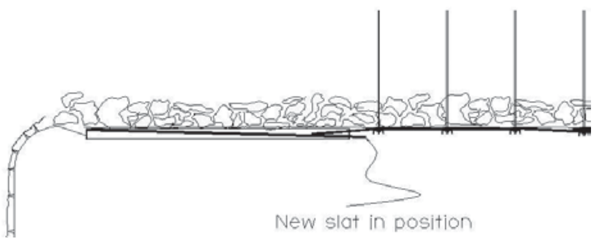

Figure 16c. McNally system – new roof slat fully inserted, overlaps last installed slat

SIMPLE CONCEPTS FOR PROBLEM SOLVING-THE MCNALLY SYSTEM

New concepts in the tunnel industry must today fill a high standard of criteria in order to be accepted in the current economic climate: They should be brilliant, fast, and cheap. The idea must be a clever one that solves a specific need or problem. It must also be fast to implement and relatively cheap to make. If all three of these criteria can be filled then the design has a good chance of surviving.

An example of this is the McNally Support System, developed for use in low cover urban tunneling or high cover tunneling where overstressed hard rock can exhibit rock bursting behavior. The system was developed by C&M McNally in Canada. It was used successfully on several projects and then modified for the Olmos Trans-Andean Tunnel in Peru. By replacing an open-type tunneling machine's roof shield fingers with an assembly of shielded pockets, many ground support difficulties can be solved.

This system solves the problem of displaced rock directly behind the roof shield that can deform the tunnel profile. The McNally support system also provides the benefit of continuous support along the roof and sides of the tunnel, retaining smaller pieces of broken rock in place and helping to sustain the natural rock arch, ultimately protecting workers from falling rock. This cost effective concept is now being installed on many hard rock machines in the manufacturing stages in such a way that it can be quickly utilized when it is needed (see Figures 16a-c and 17).

Figure 17. Steel McNally slats containing rock bursting in the tunnel crown

8 >> Conclusions

Risk aversion is a complex variable that is often a function of a society, its economic conditions, and legal ramifications. As an industry matures, such as the tunneling industry, it is more likely that designs will become more standardized. There will always be a need for relatively low cost, standard equipment to be used in less complicated geology. Conversely, there is also a need for more advanced designs on complex jobs.

The tunneling industry is unique in that our work is organic and as ground conditions become more complex, designs must necessarily evolve. If we are to tackle exceedingly difficult conditions such as high cover hard rock in the Himalayas, or mixed ground with rock below the water table, innovative design must become a more regular part of our industry.

Every year, there are more difficult and geologically risky tunnels being built, from deep subaqueous tunnels to urban jobs under low cover to very deep mountain transportation tunnels in overstressed rock. Thus, there are many opportunities.

Urban populations and especially suburban commuters are calling for more underground development of light rail, subways, and motorways. Everyone feels the need for cleaner water and that means longer distribution systems as well as efficient systems to treat sewerage. Infrastructure need is driving our most exciting engineering opportunities, and these challenges are being developed and proposed all around the world. New megacities are growing up fast in developing parts of the world, where there are infrastructure opportunities of every type.

Emerging markets such as India and Southeast Asia are where many large projects are now happening, and they are allowing new concepts to be introduced at a more regular pace. Despite this trend more industry groups such as ITAtech are needed to continue to push for acceptance of new design concepts. The tunneling industry must also look at the challenges before us, and whether certain projects are economically feasible. Extreme undersea tunnels between Alaska and Siberia, Korea and Japan, or Spain and Morocco may seem to be worthy technical challenges and among the most exciting things that tunnel designers can imagine. However, if analyzed carefully, economics may reveal that in practice surface transportation by ship may be a much better option.

AS AN EPILOGUE

It is important for those of us who have been in underground construction for the majority of our careers to pass on our feeling of pride in the industry and demonstrate the value of innovative design work. New machine concepts are not a lost art, but the way of the future in mechanized tunneling.

We should all find a way to create a structure within a company or an organization that allows for easy dispersal of knowledge through mentoring and encouragement. There is now an industry-wide need for trained and experienced personnel able to manage underground works. The responsibility to pass on the excitement of creativity to young engineers, tunnel builders, and designers, both men and women, is one that lies with all of us.

9 >> References

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