WORLD TUNNELLING

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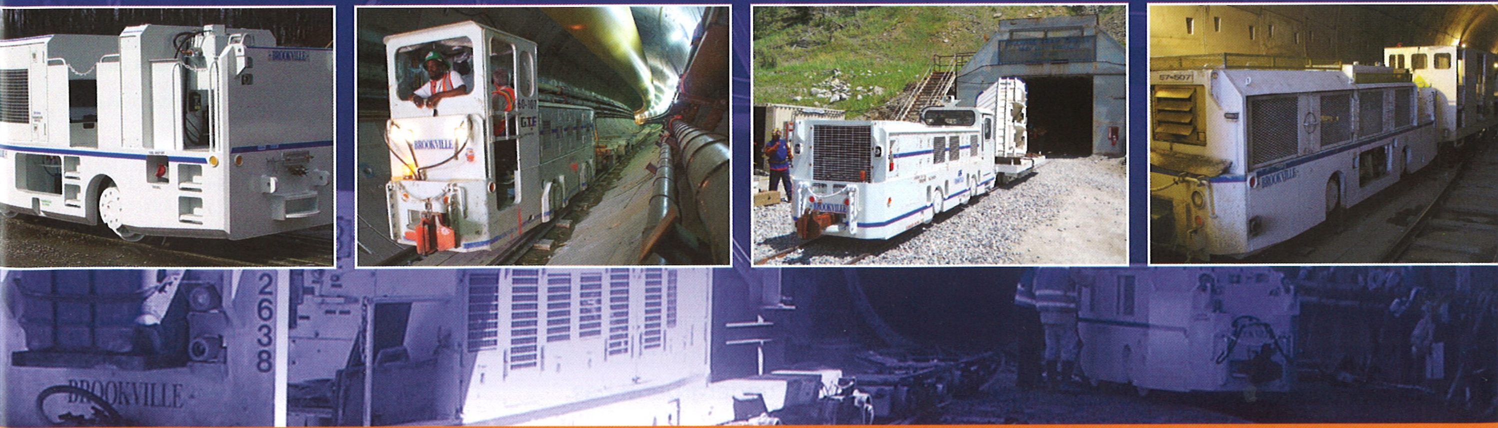
Italy

Shotcrete

Drilling muds



From headrace to tailrace

Desiree Willis of The Robbins Company looks at 60 years of TBM tunnelling and, in the process, gives a brief history of hydro-power tunnels

TBM usage on hydro-power projects has a long history, beginning with the first modern use of TBMs at South Dakota's Oahe Dam Diversion Tunnels.

Built in 1952 by James Robbins, founder of The Robbins Company, the 8m-diameter prototype utilised a dual counter-rotating cutter-head fitted with rows of drag bits and dumbbell-shaped cutters to mine through soft shale. From those beginnings, TBMs have evolved into modern-day record-breakers that push the limits of tunnelling technology.

TBMs BECOME A FIXTURE

That first TBM at Oahe Dam achieved good advance rates and subsequent machines were built for six power tunnels and seven diversion tunnels at the same project site. Refinements were made after each TBM build, allowing for better face support and faster excavations. Despite the challenges of the early bores, the popularity of TBMs, then widely referred to as 'moles', increased as word spread of their efficiency and speed.

In 1958, James Robbins died tragically in a plane crash and Dick Robbins, who had graduated from university two years earlier, took over the company at the age of 25.

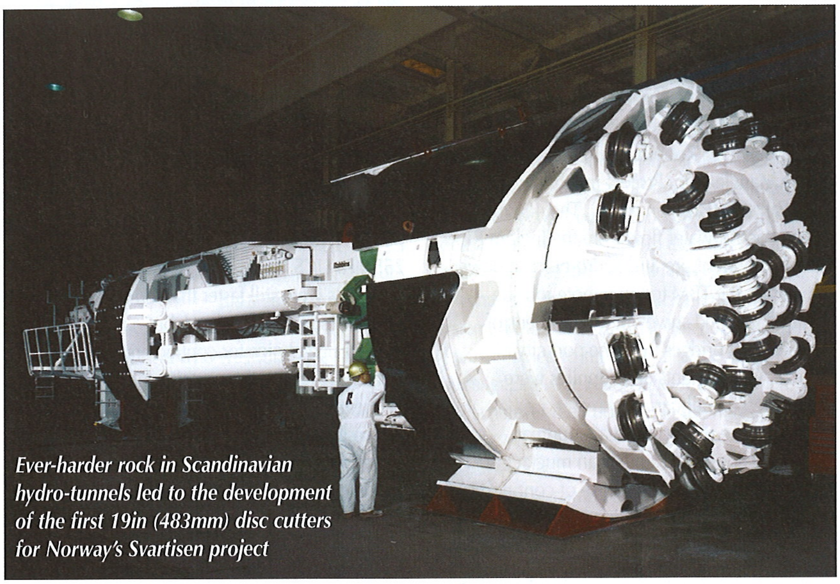
Dick oversaw the assembly of the third and largest Oahe Dam machine, a 9m-diameter giant, but after this, work became scarce. In June 1960, however, a promising lead came in for the Great Lake Power Development – a massive scheme being developed for the Hydroelectric Commission of Tasmania.

GRIPPERS MAKE THE GRADE

Robbins was contracted to supply a 4.9m-diameter main beam TBM for the Poatina Tunnel, a 6.9km headrace tunnel in mudstone and sandstone up to 118MPa UCS. The machine was built in Seattle, Washington, US, at a large shop owned by the PACCAR Structural Division. The assembly, completed in six months, included a number of unique features for the harder rock conditions.

"Up until then, the torque during drilling was counteracted by the mass of the machine. The machine sat on wide rails and the back-up was built right onto the machine," explains Dick Robbins.

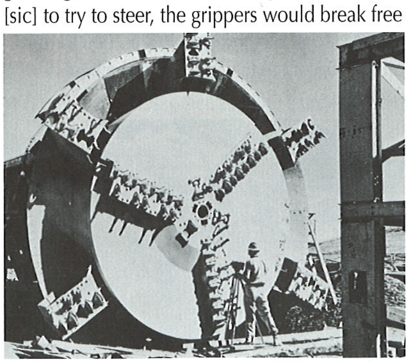
The earliest machines at Oahe Dam did not have grippers, and because of this, the rear feet tended to lift up and veer to the right, making them feel unstable.


Ever-harder rock in Scandinavian hydro-tunnels led to the development of the first 19in (483mm) disc cutters for Norway's Svartisen project

In place of grippers, hydraulic jacks shoved off from steel ribs placed towards the front of the machine – a method that also meant steel ribs had to be placed regardless of the ground conditions. Subsequent machines in smaller diameters used a type of fixed gripper, but this tended to make steering an issue.

In 1956, the Humber River Sewer Tunnel was excavated in hard, crystalline limestone using an open-type TBM incorporating 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 go straight forward. If the TBM operator were [sic] to try to steer, the grippers would break free of the walls and the machine would rotate," states Robbins. Because of this, the operators at the project had to be very cautious with the steering of the machine.


In 1952, James Robbins developed the first modern tunnel boring machine for the Oahe Dam Project in South Dakota, US

For the Poatina Tunnel in Tasmania, Robbins wanted a design that would guarantee continuous steering abilities. "The machine was to bore in hard sandstone, so we designed the first-ever articulated (floating) gripper system. It was very important for hard rock," says Robbins. The then-patented design was a success, allowing for continuous steering of the TBM, even during a push when the grippers were engaged against the tunnel walls.

Other design changes, such as permanently sealed, large-diameter bearings, were developed to improve bearing life and keep oil in, and dirt out, of the mechanisms.

The Poatina TBM began excavation in March 1961, in an industry climate where TBMs were considered experimental and drill and blast was the standard.

"World records were very important, particularly to the Australians, because they held the world record for drill and blast tunnelling at that time," comments Robbins. The Australian record using drill and blast in the Snowy Mountains topped out at about 137m/week – a record that was nearly doubled by the Poatina TBM. During a six-day working week, the machine advanced 229m, and achieved a best-shift advance of 18.2m, proving that TBMs→

could indeed excavate faster than drill-and-blast methods.

"We had our challenges, but still set tremendous rates on the job. And it was done using a completely different set of features from our earlier machines. This was because we had a great team of mechanical and structural engineers and the project owner was quite experienced," says Robbins. The success at Poatina set the stage for further TBM use in hydroelectric tunnels worldwide.

PROGRESS IN PAKISTAN

In 1963, the then largest TBM in the world, an 11.2m-diameter Robbins main beam, was built for the Mangla Dam Project in what was then West Pakistan (Pakistan today). The 4.3km tunnel was to control water flow from the Jhelum River for use in agriculture and hydro-electric power. Just getting the TBM to the remote job site required detailed surveying of hundreds of kilometres of bridges from the port city of Karachi. Components and supplies were transported by rail car.

The unique project used a Goodman coal-mine conveyor rather than muck cars in the industry's first-documented use of continuous conveyors for TBM tunnelling.

"Goodman and James Robbins had developed this design, and it had been used for coal and potash mines," says Robbins. The five TBM tunnels on the project were straight, allowing the conveyor to be re-used at all five sites; at the time, designs did not exist for conveyors to go around curves. An extensible belt was side-mounted in the tunnel, while rail tracks still allowed for materials transport and man-access. Belt tension was maintained using a belt cassette, where new lengths of belt were also added.

"They were able to operate continuously. It worked like a charm – and then the extensible conveyor was forgotten by the industry because it was perceived by contractors and owners as too much of an investment," explains Robbins.

Most of the early records were established with muck cars, and continuous conveyors were not re-used in TBM tunnels until 30 years later, when it was again demonstrated that extensible conveyors were indeed faster.

EUROPEAN BOOM USHERS IN NEW HARD-ROCK DESIGNS

Throughout the late 1960s and into the mid-1980s, hydro-power development was booming in Europe – a trend that led to increased use of TBMs, particularly for small-diameter tunnels in the 3-4.5m-range.

"There were many small-diameter, high-pressure tunnels for penstocks and tailraces in Norway, Switzerland, Austria and Italy at that time," says Robbins. In particular, a 1976 Swiss hydro project known as Grimsel tested the hard-rock limits at the time. The 4.3m-diameter Robbins main-beam machine was to excavate a penstock tunnel in alaskite and gneiss up to 255MPa UCS.

Pakistan's large-diameter Mangla Dam tunnel-boring machine used the first continuous conveyor to operate behind a TBM – a prototype that was developed by James Robbins

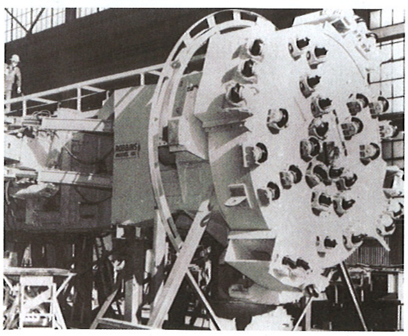
"TBMs were still faster than drill-and-blast operations in rock this hard, but not by a lot. It was a tough choice for contractors," explains Robbins. To make the machine faster, 15in-diameter (381mm) disc-cutters were developed for the Grimsel project, allowing the machine to operate more efficiently in the extremely hard conditions. This cutter diameter eventually gave way to even larger 17in (432mm) cutters for harder rock conditions and became the standard for use on larger-diameter machines.

By the 1990s, a series of challenging Norwegian rock tunnels at the Svartisen hydro-power project would push cutter diameters even further, making 19in cutters a viable option for very hard rock.

THE FUTURE OF HYDRO-POWER

Today's hydro-power projects continue to inspire innovations, the biggest example being Canada's Niagara Tunnel project. The world's largest hard-rock TBM, a 14.4m-diameter giant, was employed to excavate a third headrace tunnel below Niagara Falls.

An aggressive construction schedule required the large machine to be assembled very quickly, necessitating the development of a new TBM assembly method. Onsite First Time Assembly (OFTA), developed by Robbins in 2006 for use on the Niagara machine, offered the best solution.



Tasmania's Poatina hydro-tunnel used a Robbins TBM with the first-ever floating grippers for continuous steering

OFTA allows for initial assembly of TBMs at the job site, rather than in a manufacturing facility. The reduction in time compared with a machine that is factory-assembled, then disassembled and shipped to the job site, can add up to as much as five months of the construction process.

Similarly, the elimination of full factory assembly reduces man hours and shipping costs – a saving that can be as much as US$4 million on very large projects such as Niagara. Assembly of the TBM at Niagara was highly successful and took place in just 17 weeks, with the machine starting to bore less than 12 months after the contract signing.

Hydro projects are now specifying longer headrace tunnels and large-diameter tunnels for multiple uses, making TBMs a good choice over drill-and-blast operations.

"Much of the development in Europe has already taken place for hydro-power, with many new water, dam and hydro projects in China, India and Southeast Asia.

In recent years, The Robbins Company, under president Lok Home, has seen a hydro resurgence in countries such as Laos, Turkey and Iceland. "A lot of the world's less-developed countries have mountains and water, and need, or will need, energy. Hydro-power is a cost-effective way to obtain this energy. Therefore, we expect perhaps twice as many projects in the next 10 years as we have seen in the past 10 years," says Home.

Regarding the long-term future of hydro-power, Dick Robbins also sees a need for more technological development. He says: "The jobs are demanding, the tunnels are longer, and the rock is harder. There will be more jobs in worse conditions, such as high mountain stresses. There are, for example, plans for very long and deep hydro tunnels in the Himalayas, but to build these efficiently we need further solutions integrating rock mechanics and continuous, flexible ground support."