Slurry shield machine for Singapore Power – Handling long distance, high water pressure, and curved sections

In 2014, Kawasaki designed and manufactured 6.9-m slurry shield machines that incorporated the technologies of hard-rock tunnel boring machines, and delivered them to Singapore. These shield machines come with such features as a large-diameter roller cutter and an overcutter to enable excavating digging through curved sections and long distances under high water pressure and other challenging conditions.

Preface

Kawasaki has seen growing demand in Singapore for cutting-edge tunneling machines that can handle long distances, high water pressure, and curved sections on top of the conventional function of drilling through hard rock. Kawasaki has been supplying shield machines that can bore through hard rock since 2005. Now it has developed and delivered a shield machine that can handle these requirements. Here we take a look at that machine.

1 History of Kawasaki shield machines

Kawasaki delivered its first shield machine to the Teito Rapid Transit Authority (now Tokyo Metro Co., Ltd.) in 1957. In the 58 years since then, Kawasaki has supplied more than 1,400 shield machines. The original shield machine, which seems primitive now, was essentially a steel cylinder designed to keep soil from caving in during the excavation process and was not even watertight. The steel cylinder served as a protective structure, i.e., a

Table 1 Main specifications

Model		Rear thrust articulated machine
External diameter (m)		6.9
Length (m)		11.65
Cutter head	Power (kW)	1,680
	Rotation speed (min^{-1})	Max. 6
	Torque (kN m)	Max. 6,250
Shield jack thrust (kN)		60,000
Number of roller cutters		46 + 2

shield, which enabled underground excavators to tunnel through the ground, hence the name of the machine. Kawasaki then went on to develop a full-face, closed shield machine equipped with a pressure bulkhead for enhanced energy efficiency and safety, articulated shield machines for excavating curved sections, and other types of machines in response to a range of tunnel construction needs.

To excavate through hard rock, the machine needs to be equipped with a special cutter and structural frame built to take reaction forces. That is why Kawasaki went to work on developing equipment that could cut through hard rock with the focus placed squarely on boring. Taking development beyond shield machines, it expanded into the field of open-face tunnel boring machines.

The shield machine featured here incorporates the functions of both types of machines.

2 Main specifications and structure of the shield machine

The shield machine's main specifications are shown in Table 1. The machine is equipped with a high-speed cutterhead and high thrust shield jacks designed to excavate through hard rock and handle high water pressure.

Figure 1 shows the structure of the shield machine. The shield machine has an inverter motor-driven disk-shaped cutter head at its front end. Built to tunnel through hard rock, the high-speed cutter head is fitted with a number of roller cutters resembling abacus beads which rotate at a maximum speed of 6 min^{-1} (the maximum rotation speed for excavating soil is normally 1-2 min^{-1}). These roller cutters rotate to bore through hard rock as the shield jacks push the cutter head against the hard rock surface to

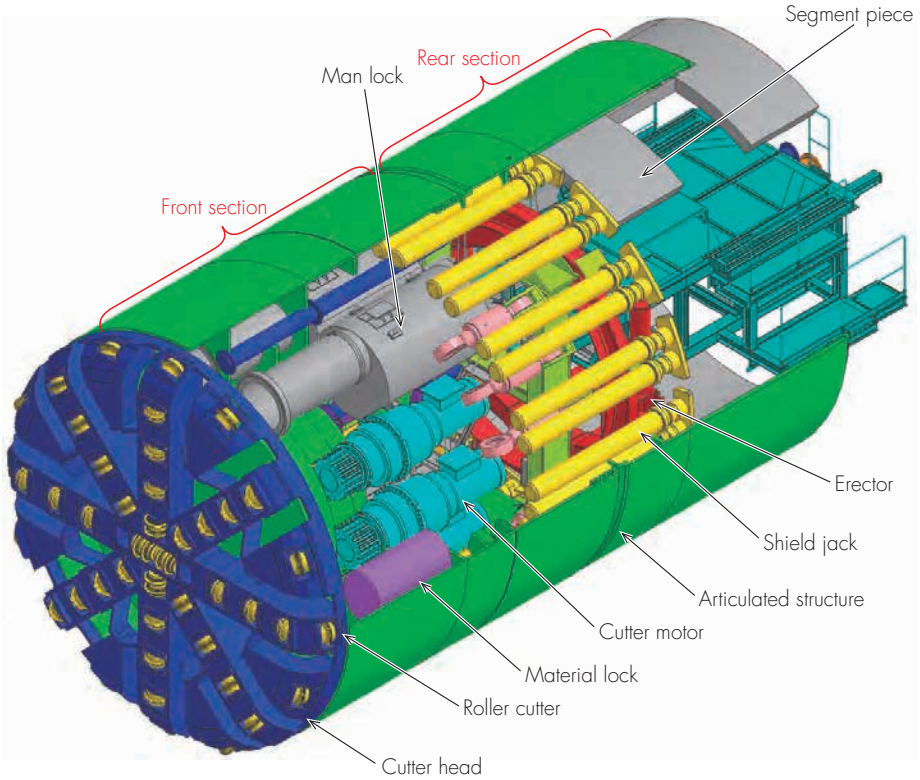


Fig. 1 Shield machine structure

move the machine forward.

The shield machine is divided into front and rear sections. This articulated design enables it to bend at the point where the machine is divided into two in order to excavate curved sections.

The machine's rear section is equipped with an erector used to assemble the segment pieces that line the tunnel.

3 Key features

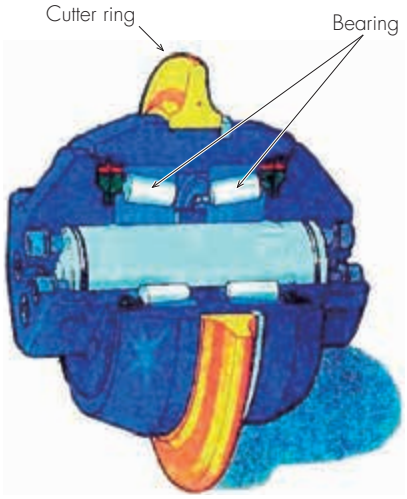
(1) Long-distance excavation

(i) 19-inch roller cutters

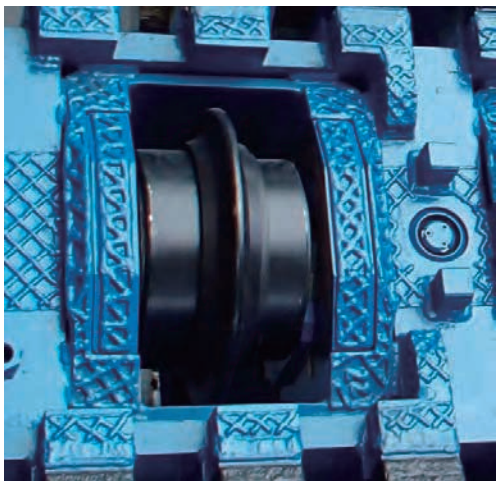
While 6-meter diameter class machines are typically equipped with 17-inch roller cutters, this shield machine employs 19-inch roller cutters to increase excavation speed and reduce the frequency of replacing roller cutters for enhanced tunnel construction performance.

Figure 2 shows the exterior view of the 19-inch roller cutter as well as a picture of the cutter that is mounted to the cutter head. Adoption of the 19-inch roller cutters allows for the use of larger bearings, thereby increasing the pressing force on the hard rock surface for speedier excavation.

The bigger roller cutter also means a larger cutter ring, which results in a higher allowable wear amount and a lower roller cutter intervention (replacement) rate.



(a) Exterior view



(b) Roller cutter mounted to cutter head

Fig. 2 19"roller cutter

(ii) Twin man locks and material lock

Since this shield machine is used for long-distance excavation, the roller cutters will still need to be replaced relatively often. When replacing roller cutters, workers may need to work in a high pressure environment in order to prevent flooding. The workers need to go into a pressure chamber known as a man lock before and after replacing roller cutters so they can acclimate to different air pressures. In order to shorten the time needed for this process, the shield machine is equipped with two man locks. It also has a material lock so roller cutters can be carried into the work area via a separate route that does not use the man locks.

(2) High water pressure capability

Since this shield machine has a closed structure, the seals must withstand an anticipated range of soil and water pressure conditions. Ensuring the performance of the high pressure tail seal that fills the gap between the machine and segments is crucial. The machine employs a four-layer tail seal, which is one more layer than found in conventional tail seals. The final layer is a urethane foam that provides optimal sealing and anti-wear performance.

(3) Ability to excavate curved sections

(i) Overcutting tool

The cutter head is fitted with two overcutting tools which are hydraulically operated by roller cutters in order to bore through curved hard rock sections. These overcutting tools are stored inside the cutter head when the shield machine is excavating straight sections. Hydraulic jacks are extended from the cutter head when excavating curved sections, and the roller cutters attached to the jack ends are used to overcut.

These overcutting roller cutters can also be replaced from the back of the shield machine, which is a huge plus when tunneling long distances.

(ii) Articulated structure

The shield machine features an articulated design with a maximum articulation angle of 3.5 degrees that enables it to handle a curve radius of 120 meters.

Postscript

Shield machines have become vital to infrastructure development across the globe. While their required specifications are getting tougher and more difficult to design, Kawasaki continues to work on developing shield machines with the kind of capabilities that meet today's needs. Kawasaki is moving ahead as it builds on its past successes to engineer better performing and more user-friendly shield machines that will lead to a brighter future.

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