Sample Chapter

Hardrock Tunnel Boring Machines
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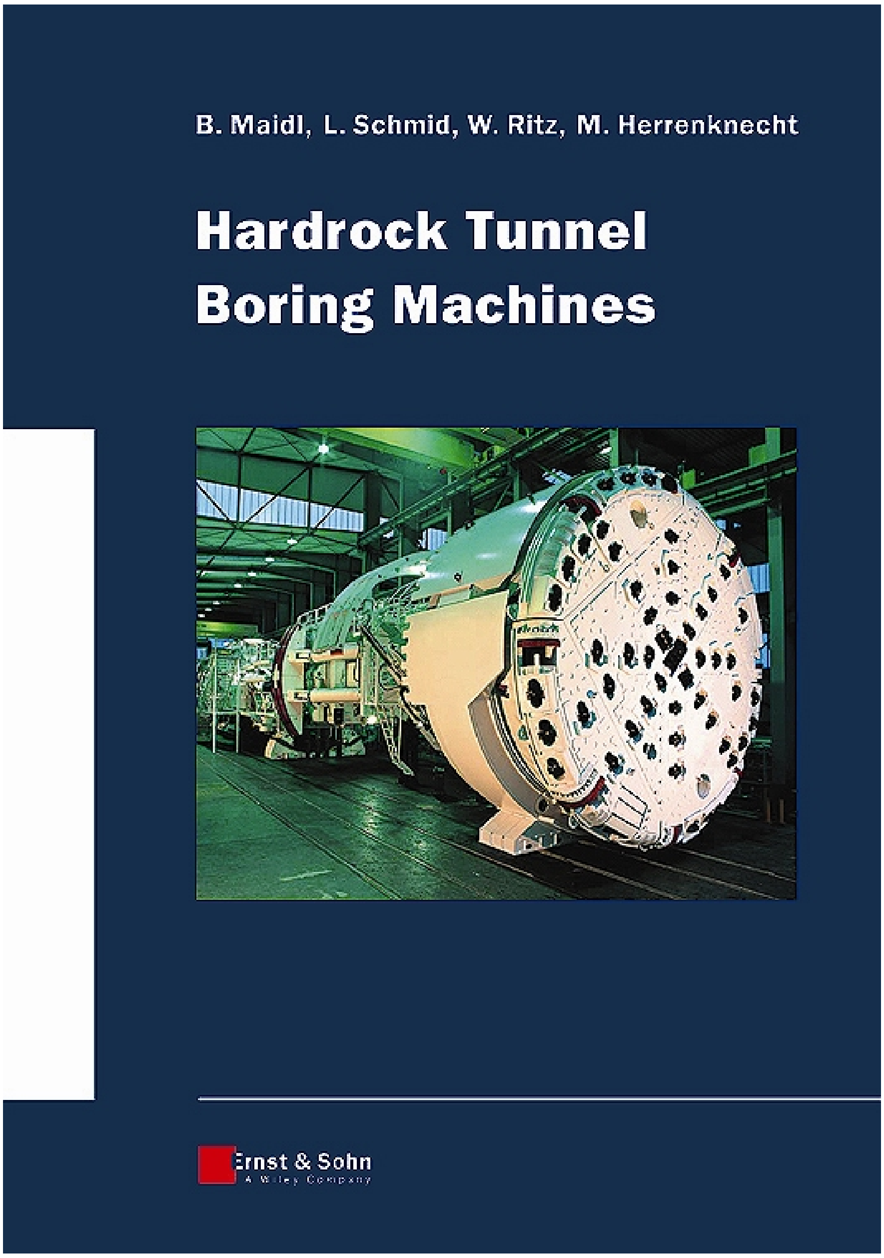

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10 Gripper TBM and Shield Machine Combinations

Two particular problem areas have to be considered in the detailed design of a TBM. Firstly, to secure the excavated cavity early in accordance with the geological conditions encountered. Secondly, the thrust required for the boring process must be produced and the support of the cutter head must be provided reliably.

In addition to these design details and the solution concepts resulting from them, this chapter discusses further tendencies in development. The classic shield for soft ground is to be equipped for work in hard rock.

If loosening of the rock structure, as is to be expected in lightly fractured rock, is expected during TBM excavation, then the support has to be installed as near as possible to the working face. That is, immediately behind the cutter head. This requirement is, particularly with small and medium diameter tunnels, a contradiction to the available space around the tunnelling machine. The consequence is a serious restriction of the advance rate.

These collapses can be dealt with by the provision of movable support in the form of a protective shield. Various special types of tunnelling machines have been developed and built for this purpose.

According to the layout of the machine, these special types can also cope with supporting the reaction forces from boring. Although the weight of the machine can be carried directly to a radial support by the rock, the thrust force and the torque can only be transferred to the rock either indirectly through a radial clamping (gripper) or directly against a segmental lining.

The question of the adequate transfer of thrust forces is just as significant as the question of support around the cutter head when deciding which solution to follow.

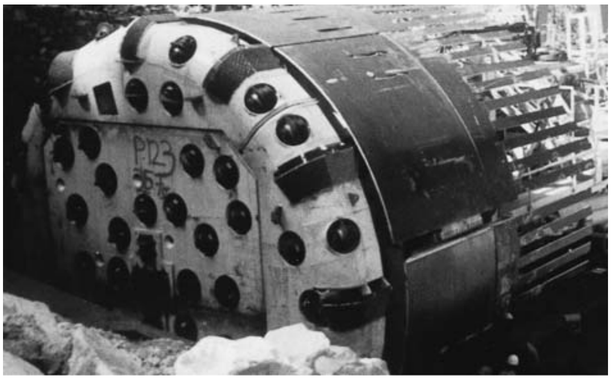
Various basic types can be categorised from the multitude of individual solutions, which approach the classic shield tunnelling machine through the choice of temporary support or represent a combination with it. This extends to the installation of roofs and side shields, through the use of a cutter head shield, and on to the use of fully shielded hard rock tunnelling machines as single or double shield.

In addition to the machine layouts and special constructions resulting from the question of rock support or clamping, further innovative combinations of TBMs with shield machines are discussed. These represent extensions of the classic shield for soft ground, which are equipped for use in hard rock.

10.1 Roof Shields

Isolated falls of rock and frequently, in addition, deformations of the tunnel section are to be expected in every tunnel excavation. TBMs are therefore equipped with roof shields, which are intended to provide protection against falling rock (Fig. 10-1 a).

a)



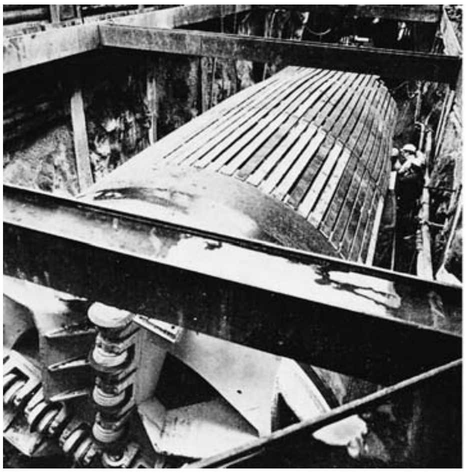
b)

Figure 10-1
Roof shields of gripper TBMs
a) Roof shield (Herrenknecht)
b) Roof shield extended with trailing fingers (Robbins)

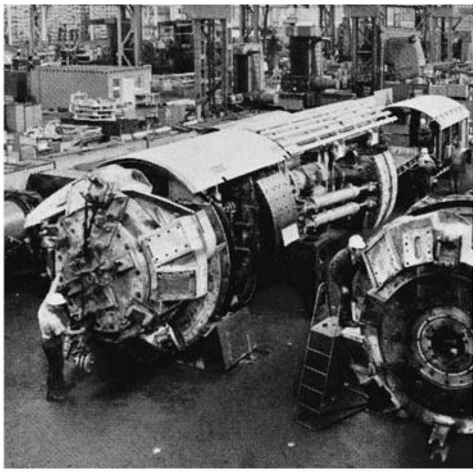
These will not, however, exert a stabilising effect on the rock with a higher supporting function. These roof shields are often extended backwards with trailing fingers, which more or less bridges the distance between the stator of the TBM and the installed rock support in fractured rock as a load-bearing element (Figs. 10-1 b and 3-3 a). A favourable property of this construction is the elasticity of the individual fingers, which are capable of holding large blocks of rock (Fig. 10-2). The roof shield is also continued as far as possible forwards in order to protect the cutter head from falling rock.

Articulated load bearing protection roofs over the entire area of the machine, which were produced in the 1970s by various TBM manufacturers like, for example, the gripper TBM for the Schwelme heading (Fig. 10-3 a), were often damaged by falling rock [120]. Hydraulically adjustable multi-part protection roofs (Fig. 10-3 b), which were pressed against the crown like with the gripper TBM in the Kielder tunnel, are also no longer used in this form. Multi-part protection roofs can today only be found in special designs like the Mobile Miner (see Fig. 3-38) and the Continous Miner (see Fig. 3-40 b).

Figure 10-2
Trailing fingers of a gripper TBM (∅ 5.2 m) in a fractured phylitic Verrucano, Ilanz II



a)



b)

Figure 10-3
Multi-part crown shield construction over the machine area
a) Gripper TBM 134-153 with static roof (Robbins), Schwelme heading, ∅ 4.0 m [120]
b) Gripper TBM TVM 34-38 with hydraulically adjustable roof (Demag), Kielder tunnel, ∅ 3.5 m [67]

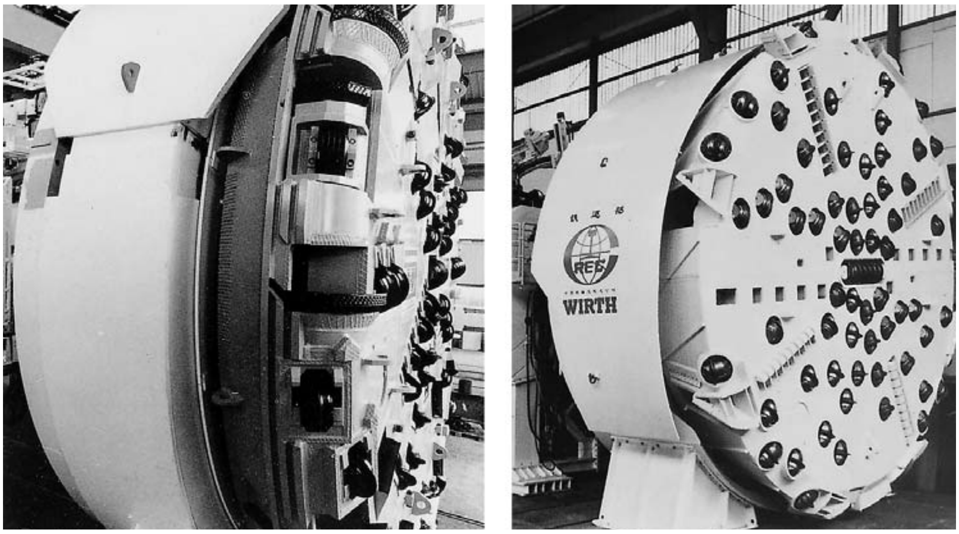
10.2 Roof Shield and Side Steering Shoes and Cutter Head Shields

While boring continues, the cutter head exerts a propping force on the working face through the attack points of the cutting tools. This propping force is, however, is only effective as long as the cutter tools attack the rock, and not at all while the machine is re-gripped, during servicing, maintenance and repair work in front of the cutter head.

A propping force can be exerted on the rock around the cutter head of a gripper machine by the roof shield and the side steering shoes or cutter head shield, whose segments can be extended radially. This propping force stabilises the tunnel wall locally and also assists the stabilisation of the working face. The cutter head is protected from falling rock around the gauge cutters and the blocking of the cutter head is prevented. The shield surfaces additionally serve to clean the invert and as a dust shield for the effective functioning of the dust removal equipment.

Side steering shoes are protection units, which are arranged behind the cutter head of a main beam TBM (see Chapter 4) and are similar to a shield. When they are arranged to cover the whole surface, the support consists of an invert shield, also called slide shoe, the side shoes arranged on rockers and the roof shield (Figs. 10-4 a and 3-4 b). The side steering shoes can be radially slewed and thus serve, like the height-adjustable invert shoe, to maintain the position of the cutter head during the boring operation.

Cutter head shields were originally only found on Kelly TBMs. Mounted on a linkage, they served only as a protection for the cutter head, with the maintenance of the posi-



a) b)

Figure 10-4
Full-surface protection equipment in cutter head area
a) Roof shield and side steering shoes main beam TBM S-155 (Herrenknecht), Tscharner, ∅ 9.53 m, 1999 [61]
b) Cutter head shield Kelly TBM 880 E (Wirth), Qinling tunnel, ∅ 8.80 m, 1997 [182]

tion of the TBM and the cutter head being primarily performed by the Kelly construction with the double clamping unit. Because of the front-heaviness of today's larger Kelly machines caused by the cutter head, the height-adjustable invert element of the cutter head shield also serves to bear the weight, so that the originally different constructions regarding support around the cutter head have converged again (Fig. 10-5).

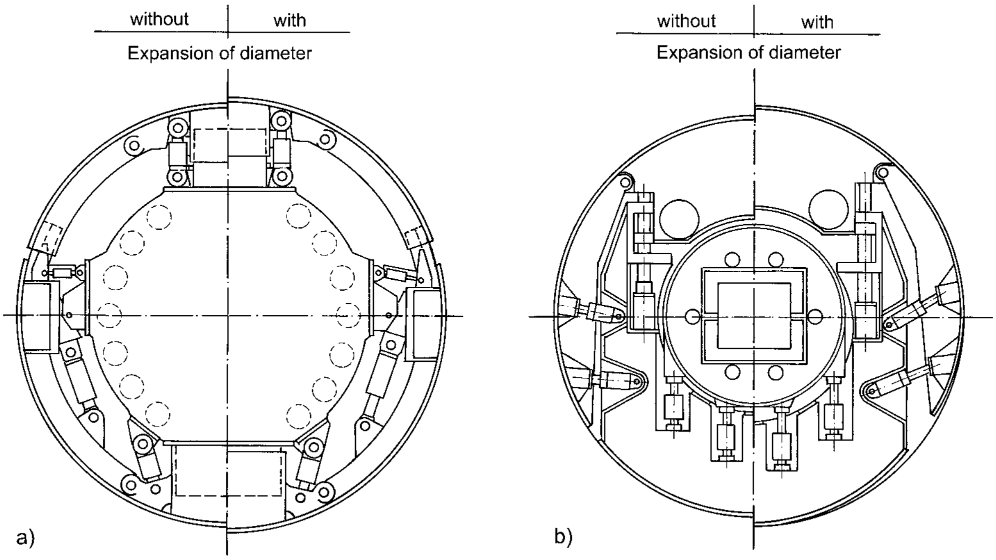


Figure 10-5
Alteration of diameter
a) Roofl shield and side steering shoes main beam TBM S-155 (Herrenknecht) Tscharner, ∅ 9.53 m, 1999 [61]
b) Cutter head shield Kelly TBM 770–850 E (Wirth), Vereina, ∅ 7.70 m, 1994 [181]

Depending on the diameter of the tunnelling machine and the resulting amount of space available, support measures like anchors or steel arches can be installed directly behind the side steering shoe surface or the cutter head shield.

10.3 Walking Blade Gripper TBM

In addition to the various types of gripper TBM discussed, special constructions have sometimes been built to meet the demands of individual projects. Out of the multitude of special constructions, the walking blade gripper TBM will be discussed in more detail here, because the use of this type of machine is often proposed for use in tunnelling through squeezing rock.

This machine has repeatedly been suggested by Robbins [123, 124, 126] for tunnelling in squeezing rock. This type of machine has so far been used only for the Stillwater tunnel in Utah, USA, and for the investigation heading for the Freudenstein tunnel.

At the Stillwater tunnel, the excavation was started with a double shield TBM (∅ 2.91 m). After the machine encountered an area of slate clay cut up by faults, re-gripping was hindered 14 times by the blocking of the gripper shield, and, at 1000 m into the drive, the machine could proceed no further; the project was tendered again. For the second attempt, the machine was rebuilt underground into a walking blade gripper TBM. The expanding blades of the shield were controlled in two groups. While one group clamped into the rock to transfer the reaction forces from the boring process, the blades of the other group were pushed forward with the TBM, and after the maximum stroke of the expanding blades of the first group had been reached, the TBM was clamped with the second group of blades and the expanding blades of the first group were pushed forward

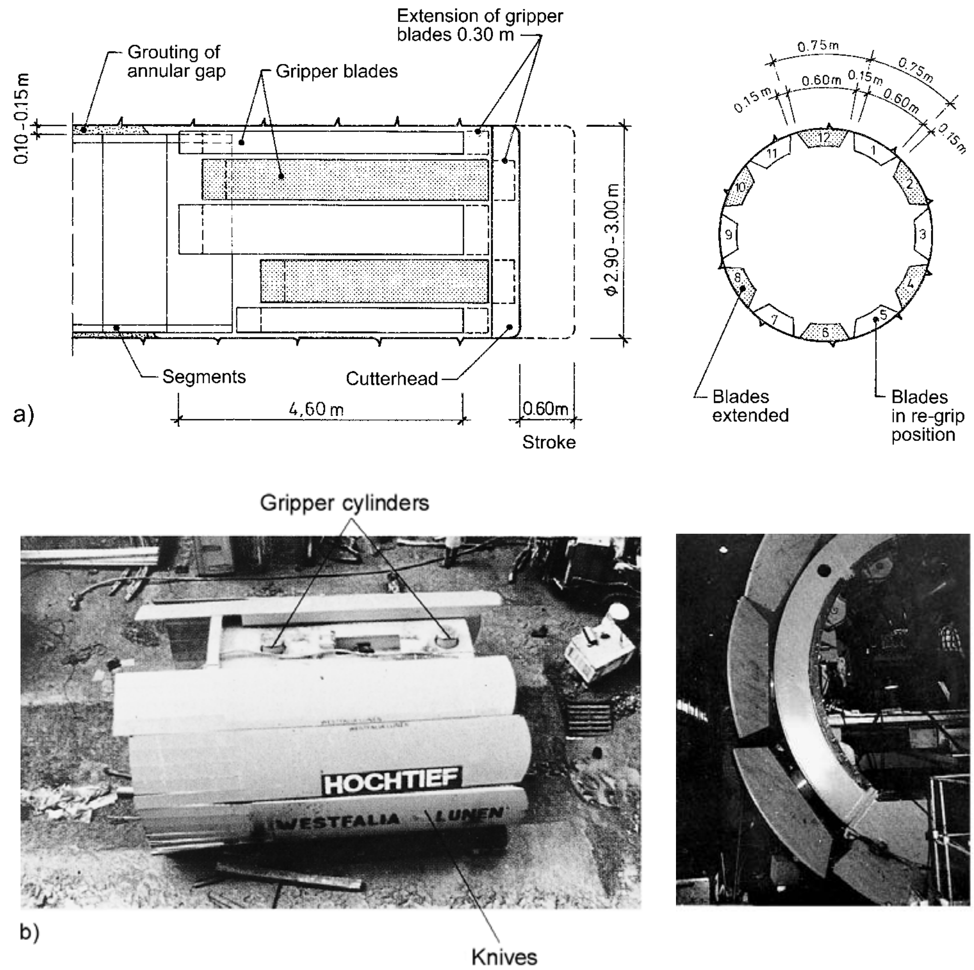


Figure 10-6
Walking blade gripper TBM
a) Blade-TBM 92-192 (Robbins), Stillwater tunnel, ∅ 2.9/3.0 m, 1983 [161]
b) Blade-TBM (Westfalia Lünen), Freudenstein tunnel, ∅ 5.4 m, 1994 [62]

with the machine. The average advance rate of this TBM was 9.1 m/d, while the gripper TBM with roof shield (∅ 3.2 m, 1.8 m long roof schield with 1.5 m long trailing fingers extension at the crown) used in the advance in the other direction achieved under the same unfavourable geological conditions an average advance rate of 41 m/d [129, 148].

The blade TBM (∅ 5.4 m) for the Freudenstein tunnel reached an average daily advance of 2.5 m in leached gypsum Keuper. The machine turned out to be extremely susceptible to water. As soon as a certain water content of the excavated rock was exceeded, the closed arrangement of the cutter head resulted in the cutter head and the bucket chutes agglutination of the muck. Tedious cleaning work with retracted cutter head and the many resulting collapses hindered the advance. Only sinking of the groundwater and additional compressed air operation made it possible for the machine to reach its end station in non-leached anhydrite rock [74]. Because of the poor advance rate and other construction delays, the use of the machine in non-leached gypsum Keuper was abandoned and the tunnel section was excavated using an additionally purchased gripper TBM with cutter head shield (∅ 5.64 m), which achieved an average advance rate of 20 m/d [82].

The experience of tunnelling in both applications of this TBM has not been able to fulfil the expectations for the machine layout. Especially the steering problems with the TBM excavation at the Stillwater tunnel, which were caused by loose rock in the unsupported area (0.15 m) between the blades (l = 0.6 m), show the difficulties of applying this type of machine. The tunnelling concept of a short-shield machine with immediate support seems more favourable under such geological conditions, according to existing experience.

For the development of mechanised tunnelling systems with yieldable support for squeezing rock (see Chapter 15.2), the machine layout of a TBM with a shield adjustable in diameter, which to a certain extent can withdraw from a squeeze situation, seems to be the only practical method, even if the advance rates of the prototypes have not been convincing.

10.4 Full-Face Shield Machines

10.4.1 Developments

The idea of tunnelling in hard rock with low stand-up time or in fractured rock with a shielded tunnel boring machine was essentially influenced by experience in Switzerland. Gripper TBMs were used there at the start of the 1970s to excavate tunnels in the diameter range > 10 m and only achieved low advance rates in the sections of the sweet water molasse, which tends to collapse. A support for the rock with steel arches was necessary and hindered the advance. The basic idea was now to develop a machine for such geological conditions, with which the dependence between the utilisation rate of the machine and the stability of the rock is minimal. This idea was implemented technically with the single shield TBM with segmental lining (Fig. 10-7). The fact that the advance process is mostly separated from the rock support makes a consistently high grade of mechanisation possible and this makes for high advance rates, even in changeable

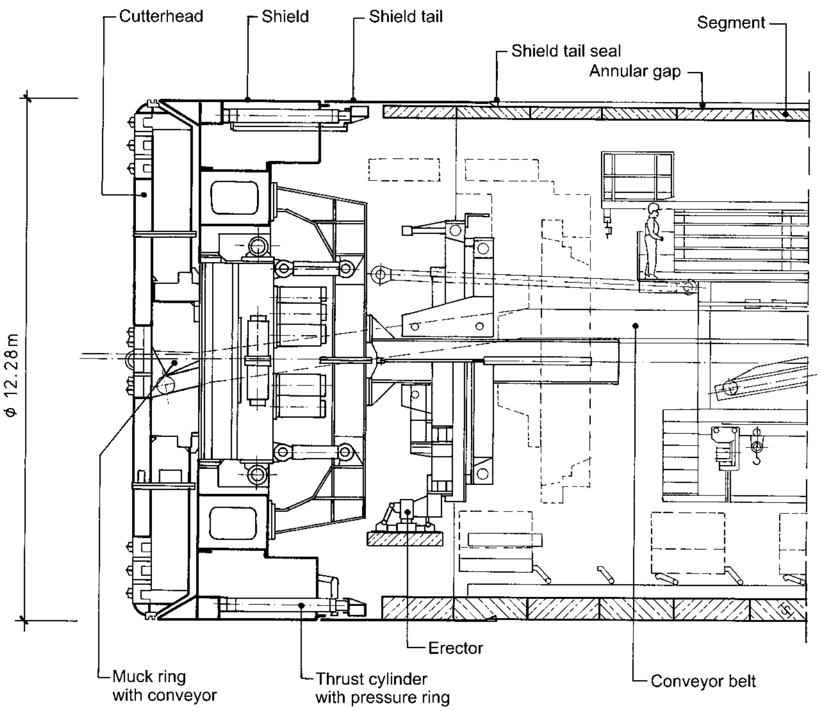


Figure 10-7
Single shield TBM S-139 (Herrenknecht), Zürich–Thalwil, ∅ 12.35 m, 1998 [61]

geological conditions. This tunnelling method has meanwhile reached a state of perfection in Switzerland, which shows in the increased advance rates. For example, the shield TBM in the southern section of the Zürich–Thalwil tunnel (1999) achieved an average advance of 26 m/d in comparison with 11.90 m for the driving of the second bore of the Gubrist tunnel (1980). The use is in no way restricted to easy-to bore rock like molasse or jurassic. Applications in alpine rocks or in gneiss have also been successful.

This experience in the range of diameters of over 10 m is certainly valid for other countries.

10.4.2 Special Characteristics

Shielded tunnel boring machines completely avoid the use of shotcrete in rock support, in contrast to the gripper TBM. Segmental lining, well known in soft ground, is used with adaptations for the situation in hard rock. The rock is never open. Geology with a tendency to collapse can usually be managed and does not cause any delay with the excavation.

This machine type also exhibits some characteristics in comparison to shielded machines for use in soft ground, apart from the method of working face support, and these will be discussed here in greater detail.

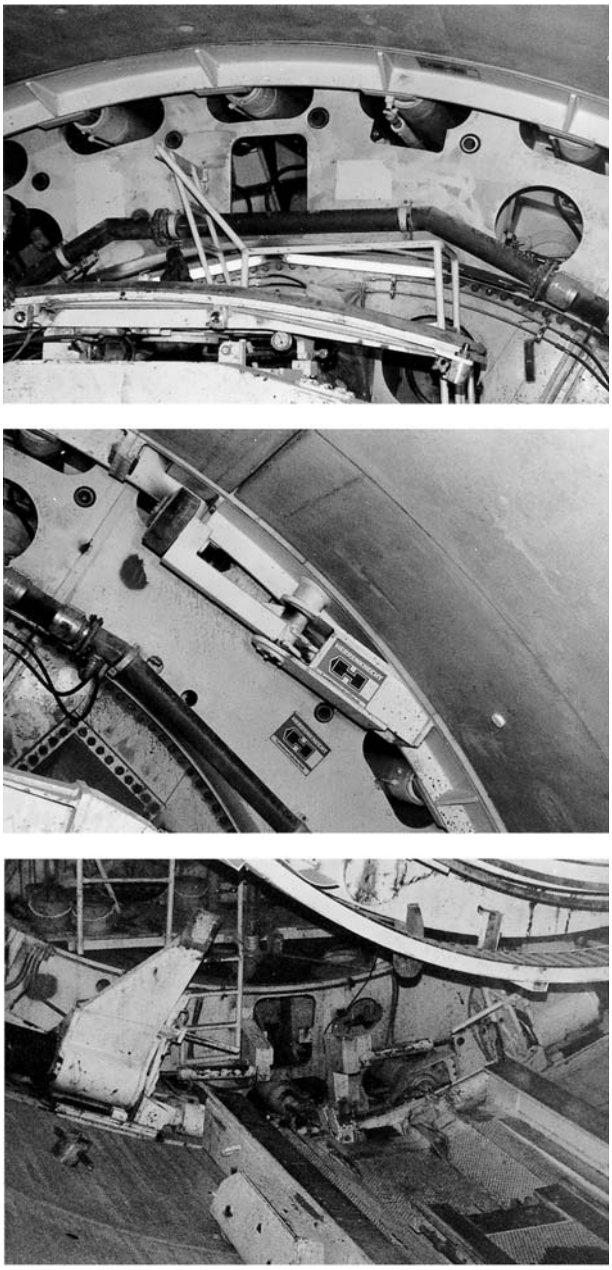
10.4.2.1 Cutter Head and Shield

The diameter of the cutter head (see Fig. 3-3 c and d) of a shield TBM is usually slightly larger than the shield. This is intended to produce an overbreak, which prevents the blocking of the cylindrical shield. The cutter head axis is placed slightly higher than centreline of the shield. This creates a small gap between the exterior surface of the shield and the crown (Fig. 10-7). In order to stabilize the cutter head without side support of the shield during tunnelling, and to ensure the disc cutters can run in their tracks without offset, two hydraulic stabilising shoes (Fig. 10-8) are located in the upper half of the shield, which can be pressed against the side of the tunnel through an opening in the shield. The use of stabilisers in tunnelling originated in double shield technology (see Section 10.5).

Figure 10-8
Stabilising shoe shield TBM S-160 (Herrenknecht), Metro Porto, ∅ 8.7 m, 1999 [61]

10.4.2.2 Thrust Ring

When shielded machines are used in loose rock, the face support requires continuous contact to the segments, which is applied by the remaining thrust cylinders during the ring installation process. In contrast, shielded hard rock TBMs with a five-part segment lining and one keystone in the invert (see Chapter 15.2) have a thrust ring between the thrust cylinders and the last segment ring installed (Fig. 10-9 a), which all cylinders press against. After completion of the stroke, the thrust cylinders and thrust ring are retracted, making space in the shield tail to install the next segment ring. The shield TBMs used in Switzerland have further devices for ring installation, like swivelling carrier rollers for placing the side segments and expanding devices for the installation of the key stone in the invert (Fig. 10-9 b and c).



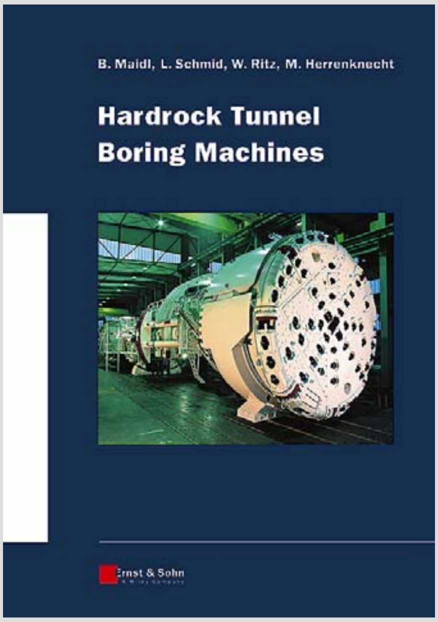
a)

b)

c)

Figure 10-9
Auxiliary device for ring installation, shield TBM, Zürich–Thalwil
a) Thrust ring
b) Swivelling carrier rollers
c) Expanding mechanism for installation of the keystone in the invert joint

BOOK RECOMMENDATION



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Hardrock Tunnel Boring Machines

This book covers the fundamentals of tunneling machine technology: drilling, tunneling, waste removal and securing. It treats methods of rock classification for the machinery concerned as well as legal issues, using numerous example projects to reflect the state of technology, as well as problematic cases and solutions. The work is structured such that readers are led from the basics via the main functional elements of tunneling machinery to the different types of machine, together with their areas of application and equipment. The result is an overview of current developments. Close cooperation among the authors involved has created a book of equal interest to experienced tunnelers and newcomers.

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