

## **Hard Rock TBM Tunneling – Technical Developments and Recent Experience**

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### **ABSTRACT**

The paper explains the working principle of modern hard rock TBMs such as Gripper TBM, Double Shield TBM and Single Shield TBM. New technical developments in this field are highlighted and experiences from recent projects around the world are shown. The presentation also highlights specific measures to deal with difficult conditions such as squeezing, water inflow or fault zones.

### **1. INTRODUCTION**

Historically, the development of hard rock tunneling machines has been closely linked to the development of suitable materials and types of cutters. Early applications often suffered excessive wear. Frederick Beaumont built two early TBMs which were used to excavate the channel tunnel in 1882 until they were stopped for political reasons. 1848m were driven on the French side and 1850m on the English side. The first modern Gripper TBMs have been built by the Robbins Company in the US in 1957. The Humber Sewer Tunnel in Toronto, Canada was built with this 3,27m gripper TBM. Single shield TBMs have evolved during the 1970s for many European mountain tunnels as they offer more protection in fractured rock at the cost of drilling performance. To balance those two requirements, the doubleshields have been developed in 1972. They have been successfully used in many projects around the world since then. Currently, the Ulrikentunnel and the Follo Line in Norway are excavated using the worlds newest generation of double shield and gripper TBM.

### **2. HARDROCK TBM TYPES**

There are different types Hardrock TBMs. They can be classified into Single Shield, Doubleshield and Gripper TBM. Single and doubleshield can build segmental lining, while gripper shields are only drilling machines and can erect anchors, beams and shotcrete lining.

## 2.1 Single Shield

Single shields are built to advance in solid or fractured rock. Like other shield machines, they use thrust cylinders (5) to advance and an erector (4) to build segmental lining (6). The rock chips which have been cut by the cutterhead (1) are lifted up by buckets in the cutterhead and drop onto the muck ring (2). From here, they fall onto a belt conveyor (7) which removes them from the TBM. The maindrive is held within the steel structure by using a hydraulic torque box (3). This allows precise control of the cutting process.

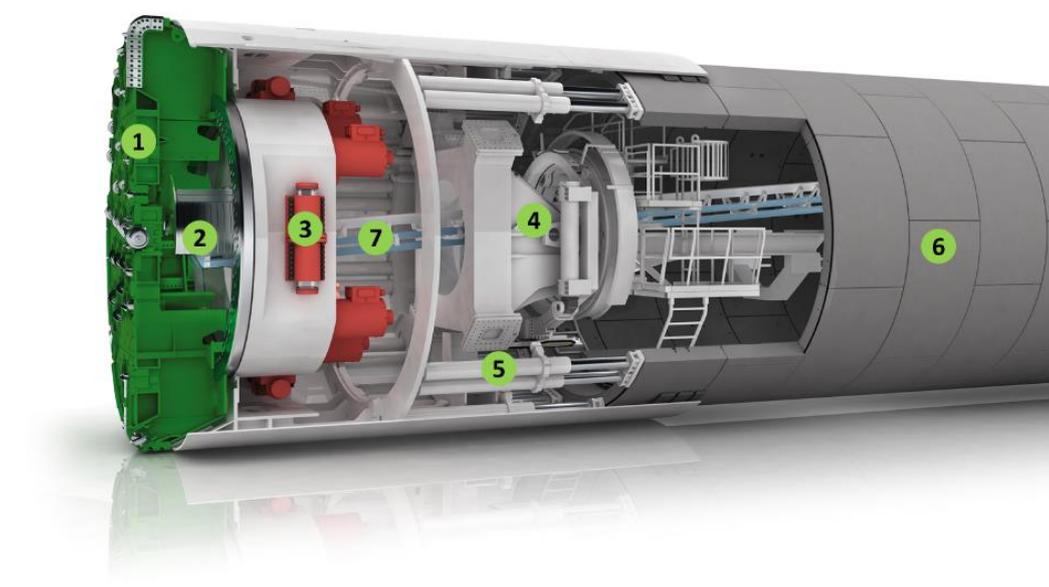


Fig. 1 Structure of a Single Shield TBM

## 2.1 Double Shield

Doubleshields have been developed to increase the production rate of TBMs in fractured rock. Excavation and muck transport work in the same way as for single shields. However, their front shield (1) is equipped with a telescopic function (2) relative to the rear shield (3). It is pushed forward by the main thrust cylinders (4) from the middleshield while the torque is transmitted by torque cylinders (7). The Thrust force is led into the ground by the gripper (8). During advance, the rear shield is fixed and by using the auxiliary thrust cylinders (6), the erector (5) can erect the segment lining (9). After completing one cycle of advance and Ring-building, the gripper is repositioned and advance can restart. This increases the productivity relative to a single shield.

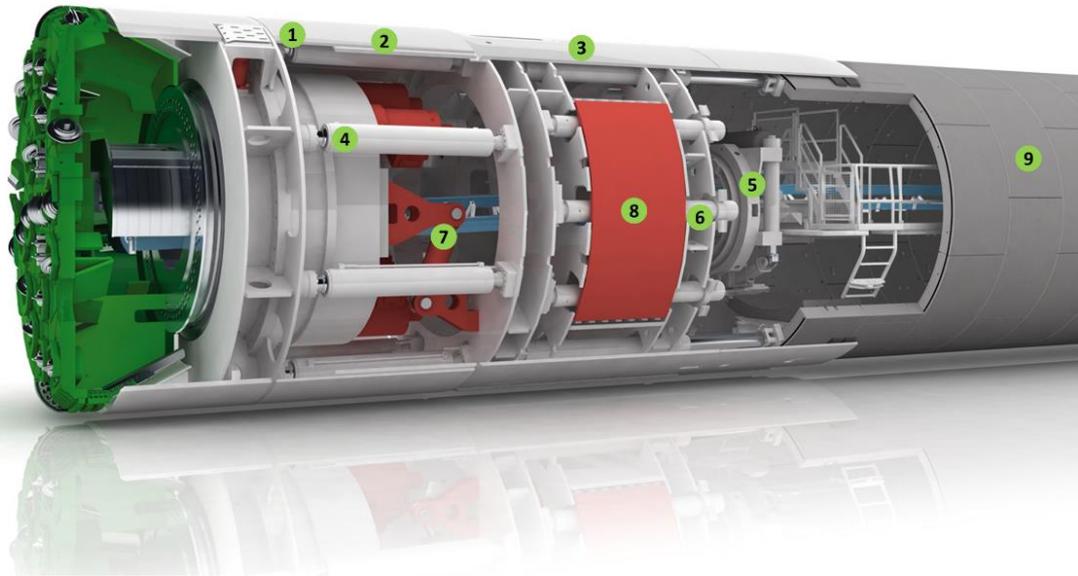


Fig. 2 Structure of a Double Shield TBM

### 2.1 Gripper TBM

Gripper TBMs are designed for high advance rates in stable hard rock. The front shield (1) holds the maindrive (3) which drives the cutterhead (2). Hydraulic cylinders (4) allow adjusting the size and alignment of the shield. The shield is at the tip of the main beam (5) and is pushed forward by thrust cylinders (7) which lead the force into the ground through grippers (8). Hydraulic feet (9) hold the TBM while resetting the gripper. The TBM is equipped with drilling machines (6) to install rock anchors. This is necessary to secure the geology safely.

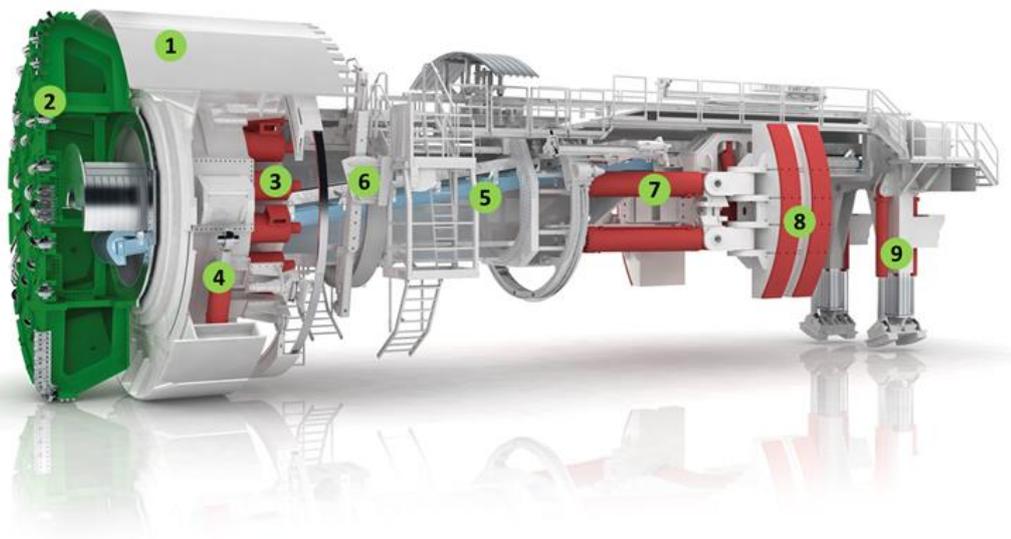


Fig. 3 Structure of a Gripper TBM

### 3. TOOLBOX FOR DIFFICULT GEOLOGY

TBMs have to master difficult ground conditions. Especially gripper TBMs are exposed to the geology and difficult conditions must be actively countered. Difficult conditions can be caused by high overburden, which induces high stresses into the mountain. In such a scenario, rock burst and swelling can be the consequences. Both can be potentially dangerous for workers and machine. In fault zones, other challenges are present as well. Fractured and weathered rock conditions may lead to difficulties excavating the rock for the cutterhead. Also such conditions may lead to heavy water inflow and instabilities. Therefore high dewatering capability and support installation become necessary.

#### 3.1 Advance Drilling

Advance drilling is a key technology in shields as well as gripper TBMs for difficult ground conditions. The drilling rigs are permanently mounted on a ring carrier beam behind the shield. Therefore, the mobilization time is low and the rigs can be used for inclined or horizontal drilling at any time. Drilling can be done for geology investigation but also to inject grout into the rock for stabilization. Advance grouting may be necessary to reduce water flow and increase rock stability for the passage of the TBM.



Fig. 4 Advance drilling rigs behind the shield

### 3.2 Support Installation

In weak rock conditions, the tunnel must immediately be supported to guarantee stability and safety for men and machine. Modern Gripper TBMs are equipped with efficient logistics systems which allow the convenient transport of support material to the L1 area. In this area, ring beams and wire mesh can be installed and fixed with rockbolts. Immediately after installation, shotcrete can be applied. The L1 area is therefore equipped with wire mesh erectors and drilling rigs for rock bolting. A mobile shotcrete arm allows the application of shotcrete immediately after installation of the support. To compensate for squeezing rock, the support system can be outfitted with compressible soft sections, which absorb the movement and protect the stiffer components of the support.



Fig. 5 Support installation behind the shield

### 3.3 Extendable Roof Shield and Excavation Diameter Adaption

Squeezing rock conditions lead to a risk of jamming the machine. Two main countermeasures are implemented in state of the art hard rock TBMs. Firstly the excavation diameter can be adjusted according to project requirements. In order to increase the disc cutters track radius, the gauge cutters are mounted with a modified fixing piece. This raises their radius by up to 50mm. If more is required, it is possible to

perform temporary modifications on the housings as well. Additionally, a torque box maindrive can be used to vertically adjust the cutterheads position and create more overcut on one side.

The shield can be adjusted to modified cutting diameters as well. The individual steel sections of the shield can be hydraulically moved laterally and vertically to match the cut contour. Also the maindrive can be lifted. This kinematic structure means, that the operator can always match the shield to the geology requirements.

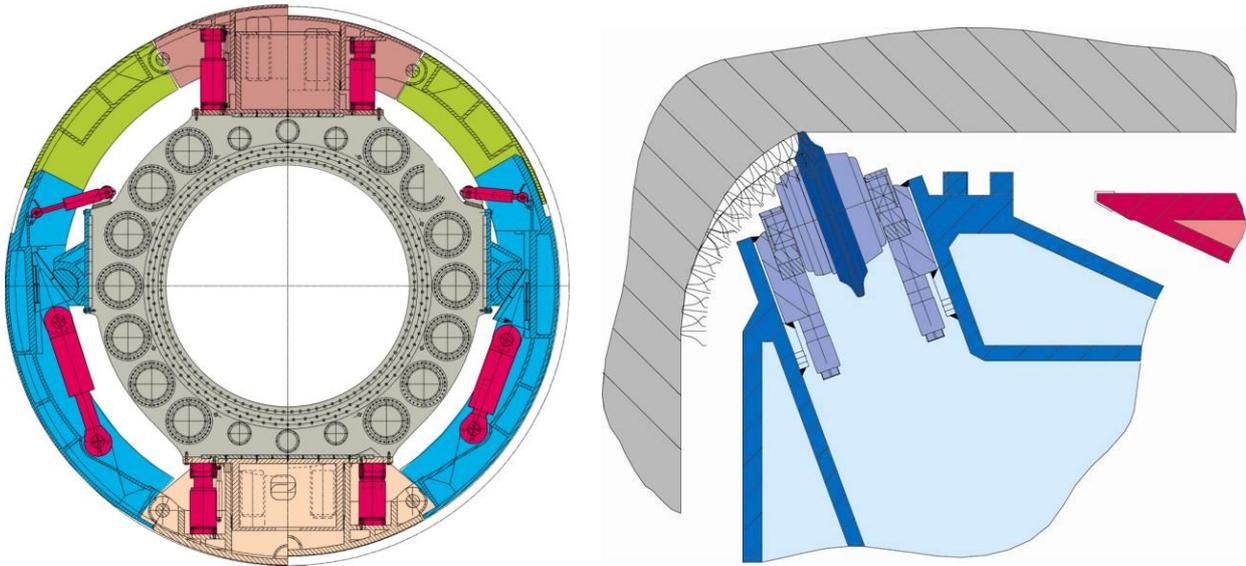


Fig. 6 Adjustable Shield Structure (left) and Overcut Increase (right)

### 3.4 Cutter Monitoring

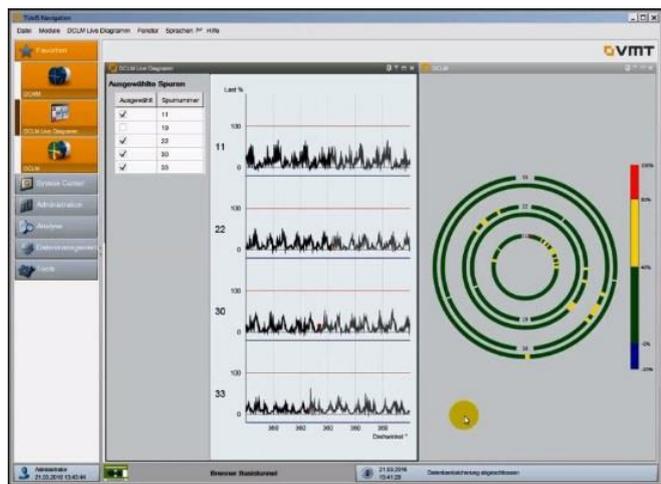


Fig. 7 TBM Cutterhead with Cutter Monitoring (left) and Cutter Monitoring Screen (right)

Knowing exactly, what happens at the tunnel face increases strongly the productivity as well as the safety of a jobsite. A very efficient way to gain information on the processes at the face is cutter monitoring. By equipping the disc cutters with sensors for rotation, force and temperature, it is possible to detect blocked cutters before damages arise, as well as optimize the cutter change patterns and advance parameters. Furthermore, the data creates an electronic map of the rock which has been drilled. This information is very valuable to project geologists.

#### 4. FOLLO LINE DOUBLESIELD

The Follo Line is a planned 22.5-kilometer (14.0 mi) high-speed railway between Oslo and Ski, Norway. Running parallel to the Østfold Line, it will be engineered for 250 km/h. Terminal stations will be Oslo Central Station and Ski Station. Most of the line, 19 kilometres, will be in a twin tunnel, which will be the longest railway tunnels in the country. The tunnels are almost exclusively built in tonalitic to granitic gneiss. Rock hardnesses are between 100 and 220MPa. Abrasivity is extremely high.

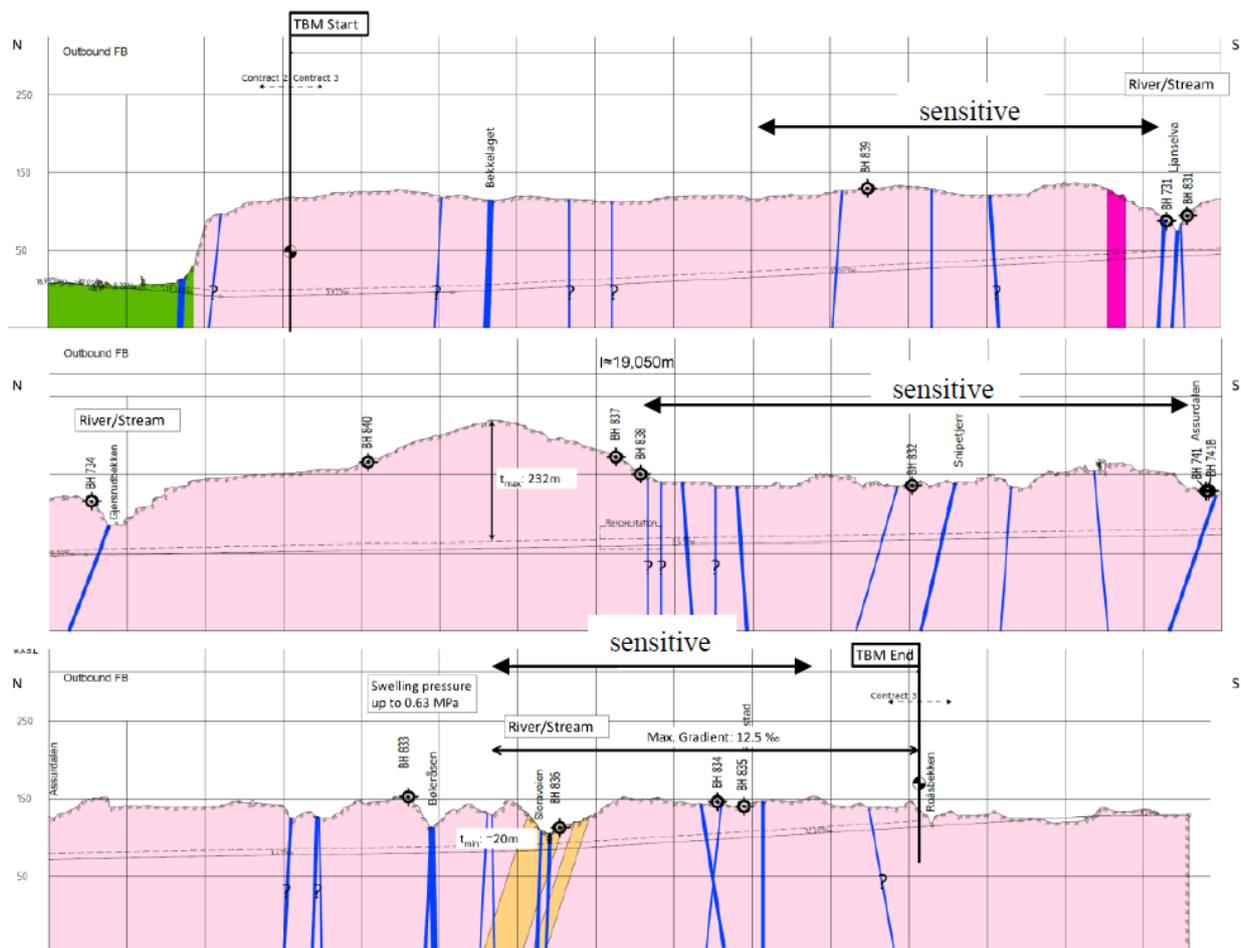


Fig. 8 Geological Cross Section of Follo Line Project

As there are a number of fault zones as well as surface water, the doubleshield machine has been equipped with extensive drilling capabilities in order to seal the ground with injections if necessary. Furthermore, around 300m<sup>3</sup>/h dewatering capacity have been considered. Herrenknecht has delivered four Doubleshield TBMs to the Project, named S-980 to S-983. The machines feature high performance logistics systems with MSV supply and tunnel belts. Together with the state of the art TBM design, the logistics system leads to very high performance of generally more than 100m per week.



Fig. 9 Doubleshield TBM for Follo Line

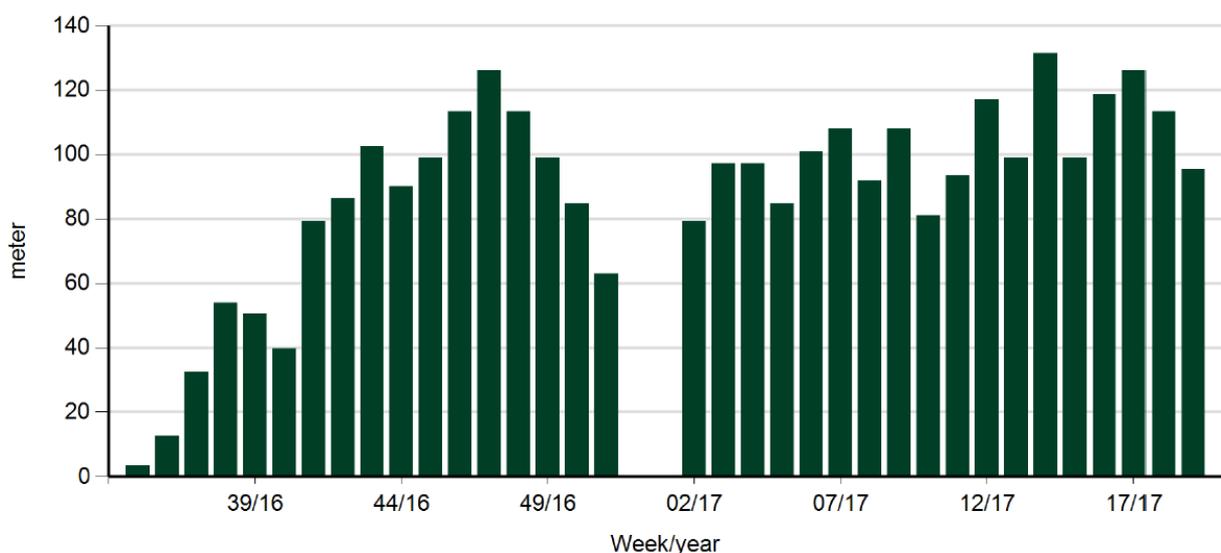


Fig. 9 Performance of the first Herrenknecht Doubleshield in Follo Line

## 5. ULRIKENTUNNEL GRIPPER TBM

The Ulriken Tunnel a railway tunnel on the Bergen Line between Bergen Station and Arna Station in Norway. The 7,670-meter long tunnel runs under the northern part of the mountain Ulriken in Bergen. Currently a parallel, second track is under construction. The geology is mainly made up of Gneiss with a hardness between 120 and 200 MPa. Generally the CAI values lie between 4.5 and 5.5. Therefore the geology can be considered as very abrasive. A number of smaller fault zones has to be passed.

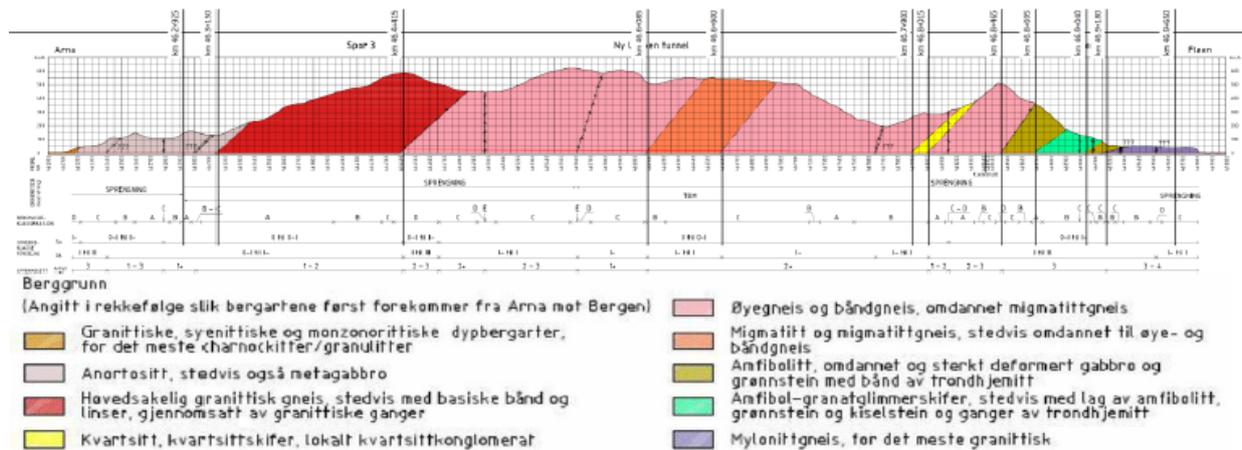


Fig. 10 Geology of the Ulriken Tunnel

Currently more than half the tunnel has been bored successfully using a Herrenknecht Gripper TBM. The machine diameter is 9.3 meters with a total thrust force of 27MN and a Gripper Force of 72MN. The Cutterhead is driven by an electric maindrive with 10MNm nominal torque and 16MNm breakout torque. It is equipped with 62pcs 19” Disc cutters to excavate the rock.



Fig. 11 Herrenknecht Gripper TBM During Assembly

The project performance is very good. Despite the very hard geology, an average performance of more than 100m per week has been reached. The penetration rates have been in line with theoretical values between 3mm/rev and 8mm/rev. The daily maximum advance has been 37m. The tunnel excavation will be finished well on schedule.

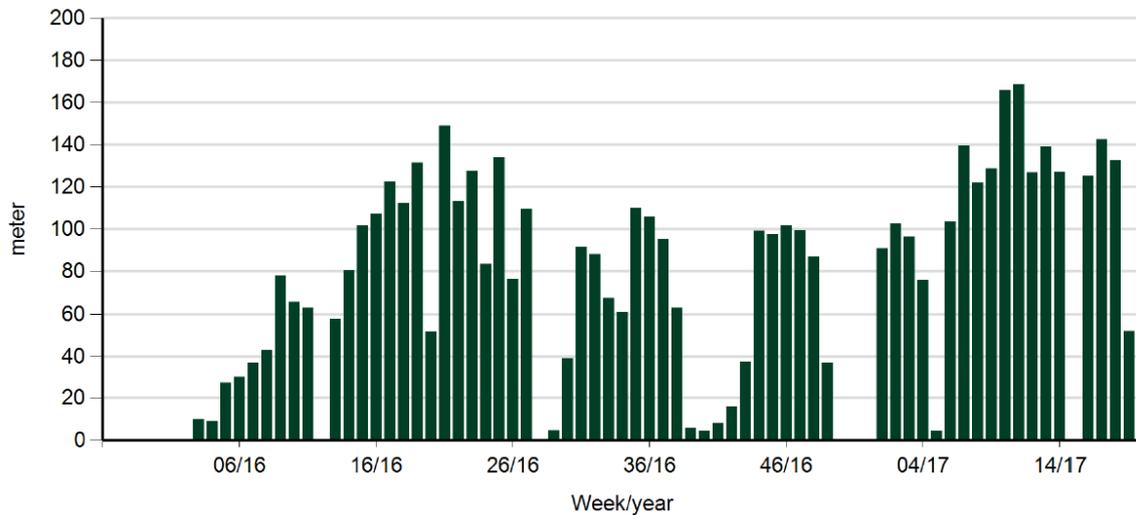


Fig. 12 TBM Weekly Performances at Ulrikentunnel

## 6. CONCLUSION

Recent years have shown remarkable advances in TBM technology and several related fields. This has allowed projects in difficult conditions to be executed and completed on schedule. The newest generation of hard rock TBMs which are used on the Norwegian projects in Oslo and Bergen are outstanding examples of this development. In the future, the industry sees more high performing hard rock tunnel projects.

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