

# **Choice of TBM type for mountain tunnelling under very poor geological conditions: Hybrid, Slurry, Epb, Dsu, Convertible Tbms**

**Remo Grandori<sup>1</sup>, Antonio De Biase<sup>2</sup>, Marco D'Ambrosio<sup>3</sup>**

1 President Seli Overseas Spa, Piazza F. De Lucia, Rome, Italy, r.grandori@selitunnelling.com

2 Technical Director Seli Overseas Spa, Piazza F. De Lucia, Rome, Italy, a.debiase@selitunnelling.com

3 Chief Engineer Seli Overseas Spa, Piazza F. De Lucia, Rome, Italy, m.dambrosio@selitunnelling.com

## **ABSTRACT**

Rock tunnelling under mountains, high covers and in very poor geological conditions might cause major problems to the advance of a TBM, especially in the most critical conditions. To improve the capability of the TBMs to cope with the adverse conditions typical of these applications, the traditional open gripper TBMs evolved to Double Shield in the seventies and to Double Shield Universal at beginning of the 21<sup>st</sup> century. In parallel the technological improvements and innovations in soft and mix ground tunnelling of the EPB and Slurry TBMs in the last 30 years, extended the capability to control face instabilities and water inflows under a wider range of geologies. Further to the above, in an attempt to combine in one single TBM the capability to work with different operating modes, several hybrid or convertible TBM types have been developed. Nowadays several different TBM types are available in the market and, understandably, the choice of the best type for a specific application became quite complicated. This choice is critical and does impacts the entire tunnel design (typical section, support, lining, alignment, schedule) as well the project cost and construction risks. In an attempt to provide a basic guideline to select the best TBM types for the different possible applications in mountain tunnelling, this paper describes the main design features of the different types of TBMs available on the market and their preferred field of application. The above based also on several recent applications under critical geological conditions.

## **1. INTRODUCTION**

Tunnelling under mountains has been the field of application of the first TBMs when this technology was initiated more than 60 years ago.

Initially TBMs were utilized essentially to excavate long tunnels in good rock with limited rock supports required. For these application Open Grippers TBMs were the only type of machines employed. Double Shield TBMs were introduced in the market in the early seventies with three main targets and the challenges that these application may pose to designers and contractors: (a) Increase the TBM performances in term of advance per day thanks to the ability to erect a segmental lining simultaneously with the excavation phase, (b) be able to advance through unstable and disturbed rocks under the protection of the shields and (c) provide a finished tunnel by installing a precast lining as the TBM advance. In 2003 SELI developed the design of the Double Shield Universal (DSU) TBM as an evolution of the original Double Shield TBM design.

This new TBM design was targeted to improve: the TBM capability to advance through squeezing/converging rock formations under high cover, the telescopic joint design (allowing by such to operate the machine in double shield mode in very weak rock), the capability of the TBM to investigate and treat the ground around and ahead of the tunnel face.

In the latest years, the application of new TBM types have appeared on the market and started being employed in mountain tunneling projects. Sometimes they are an enhanced version of the “classic” types, in other cases they borrow significant features typical of the soft soil TBMs.

## **2. THE CHALLENGES OF MOUNTAIN TUNNELLING**

In mountain tunneling the following phenomena might occur: seismicity & asymmetric stresses, hard and/or abrasive rock, high water inflow, wedge instability and rock fall, caving, squeezing, karsism, spalling and rockburst, presence of harmful gases and geothermal phenomena. In addition to that, it is necessary to deal with the difficulties of effective geology review resulting from the problematic prediction of the geology at depth, with few boreholes with core recovering and often not deep enough or at proper location and with the usual lack of many rock outcrops.

The reasons above make rock tunneling under mountains, especially for long tunnels where wide range of conditions with very severe criticalities can occur, an activity requiring not only the right technology, but also know how and experience in this specific field.

This paper focuses on the TBM choice in relation to the cases of poor rock conditions and large water inflows.

## **3. TBM TYPES**

In general, typical hard rock TBMs work in “open excavation mode” at the atmospheric pressure and without any balancing pressure (soil/earth/slurry) to stabilize the front of excavation while EPB and Slurry TBMs work in “close excavation mode” applying a balancing pressure to the front of excavation in order to stabilize the front of excavation, limiting also the effects on the hydraulic rock mass conditions. The excavation in “open mode” is commonly carried out by extracting the spoil from the Cutterhead /Excavation Chamber through a muck conveyor while the excavation in “close mode” is carried out by controlling the extraction of spoil from the Excavation Chamber with screw conveyor and/or through a slurry pumping system (the controlled variability of the flow extracted from the Excavation Chamber allows the regulation of the balancing pressure).

In between the two main types, there are several type of machines able to work either in “open mode” or in “close mode” and according to the TBM manufacturer they are designated with different names (Convertible, Dual Mode, Hybrid, Crossover, Variable Density, etc.), that often generate confusion in the market. To approach the mountain tunnelling, in the past, were implemented special design features and special devices on the typical hard rock machines (able to excavate in “open mode” only). Over the last few years in fact, the trend of the manufacturers is to develop, also for mountain tunnelling, TBMs for excavation in “close mode” or able to work in both ways.

TBM types hereby considered are: Open Gripper, Single Shield, Double Shield, EPB, Slurry, Hybrid, Convertible.

### **3.1. Open Gripper TBMs**

Open Gripper TBMs, allow fast advancement when in medium to high rock strengths and therefore are an ideal solution for unlined tunnels in stable rock formations. TBM entrapment risk in squeezing rock is very low since there is no closed shield and overcutting is possible. In case of fractured rock

conditions, immediate rock support measures are installed behind the Cutterhead (rock bolts & nails, steel mesh, steel arches), often through a finger shield that offers protection for the personnel, while shotcrete is usually applied in the Back Up area (within a distance from the front face depending on the rock mass stability).

On the contrary, in case of soft and unstable rock, gripping operation becomes difficult and safety for the personnel is reduced unless pretreatment is performed. Additional investigation through probe drilling, water drainage and pre-grouting treatment of the rock mass shall be activated from the machine. Incoming water shall be drained and pumped away from the machine where the rock mass permeability is not enough reduced through pre-treatment.

### 3.2. Single Shield TBMs Open Mode

Single Shield TBMs (SS TBMs) have the simplest possible configuration among the shielded machines. TBM obtains the necessary thrust to press the cutterhead on the tunnel face by pushing against the precast lining, installed in the tail shield in alternate phase with the excavation. Due to their simplicity, such TBMs have usually advantages from the operational and maintenance point of view, but in case of squeezing and convergence, ground overboring capability is limited. In presence of unstable front face blocking the cutterhead rotation, they have reduced/ no capacity to it pull back from the face to start again boring (after stabilization of the excavation front) and their advance rate in good/hard rock is limited by the longer advance cycle (ring-build after excavation without overlapping). On the contrary, they allow quicker and more efficient probe drilling investigation and drilling for rock mass consolidation in the rock mass through the shield and the front.

A special SS TBM has been recently delivered by Robbins for Rondout West Branch Bypass Tunnel, where fractured and faulted rock mass with high water inflows at high pressures are expected. The TBM is designed to handle high water inflows at pressure over 20 bar by means of extensive probing ahead and pre-excitation grouting equipment and is equipped with a continuous and an emergency pumping system for 50l/s and 150l/s respectively. This TBM is meant to be sealed quickly in the event of a sudden inrush of water and is provided with an emergency inflatable sealing system to protect the main bearing, a solution becoming always more frequent in projects with potential high pressure water. Based on the expected water inflows and on the geotechnical rock mass properties, patterns for probe holes and for pre-excitation grouting will be applied.

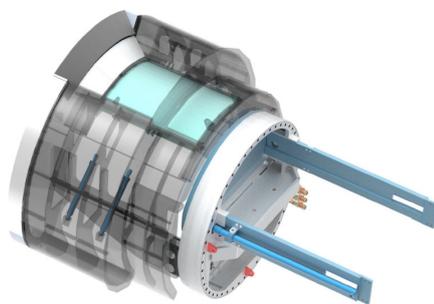


Figure 1. Detail of Sealable Robbins TBM for Rondout

**LEGEND:**

- INITIAL PROBE HOLE/PRIMARY PRE-EXCAVATION GROUT HOLE
- ⊙ VERIFICATION HOLES/SECONDARY PRE-EXCAVATION GROUT HOLE
- △ VERIFICATION HOLES/TERTIARY PRE-EXCAVATION GROUT HOLE
- VERIFICATION HOLES/QUATERNARY PRE-EXCAVATION GROUT HOLE

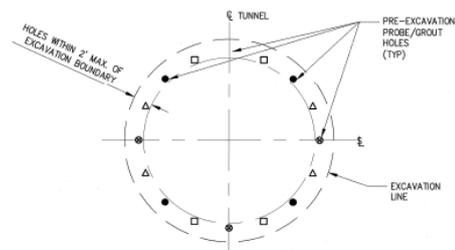
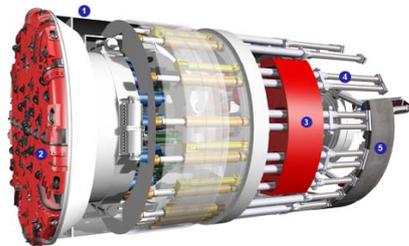


Figure 2. – Typical Probe/Grout hole pattern

### 3.3. Double Shield TBM

Double Shield TBMs (DS TBMs) can be operated both in Double shield mode for maximum advance rates and in Single Shield mode when gripping is not possible. DS TBMs have some advantages in respect of SS TBMs when boring under very critical rock conditions. Namely: can advance faster when gripping; telescopic shield can be opened or closed to release material pressure on the shields; forward shield can be moved backward in case of collapsing material at the front to avoid cutter-head blockage and proceed with rock mass treatment; active driving system allows better steering control in mixed face conditions and very weak rock mass.



**Figure 3.** DS TBM 1-front shield; 2- Cutterhead; 3-gripper pad; 4-auxiliary thrust cylinders; 5-segment lining



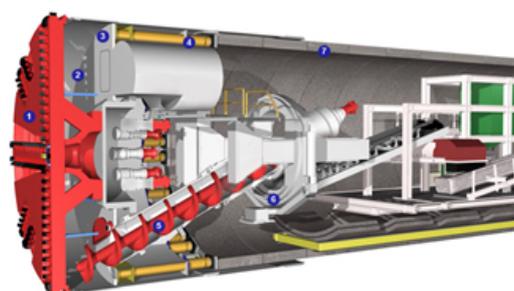
**Figure 4.** Kishanganga project SELI DS TBM

The design of these machines has developed in the direction of the Universal DS TBM type, as in the case of Abdalajis Tunnel East (Spain), where SELI was actively involved in the construction as partner of the Dragados-Tecsa-Seli-Jager Joint Venture. The 10m diameter DSU Mitsubishi TBM was designed with special features: total TBM length in the range of 11 m, i.e. equal to the length of a single shield TBM of same diameter; high conicity to allow the TBM advance also in squeezing ground; new telescopic articulation design to eliminate the problem of packing the joint in loose ground; overcutting facilities to increase the gap between the rock and the segments in squeezing ground.

A Universal DS TBM manufactured by SELI was employed in the challenging Kishanganga Hydroelectric Project in India in the Himalayan Mountains facing exceptional squeezing conditions as well as heavy loads on the segmental lining due to potential high water pressure. The 15km long TBM tunnel under high overburden (>1500m) was excavated by SELI using a 5,2m diameter Universal Double Shield TBM with exceptional performances.

### 3.4. EPB TBMs

The EPB TBM are Single Shield TBMs where the front of excavation is sustained into the excavation chamber by applying a balancing pressure with the same conditioned excavated material. EPBs have been originally introduced in the tunnelling industry to excavate in cohesive soils.



**Figure 5.** Typical arrangement of EPB TBM

An EPB type of TBM, if properly designed, will have advantages on open type TBMs (gripper, SS and DS TBMs), when boring through Poor to Very Poor Rock mass conditions (rock IV-V of Bieniawski Rock Mass Classification), and in dealing with unstable faces in presence of low ground water pressures. On the other side, when facing highly unstable faces associated to high pressure waters inflows, an EPB TBM will be un-capable to advance without the prior execution of pre-treatments of the ground and in general will be less flexible than a DS TBM in the very extreme conditions.

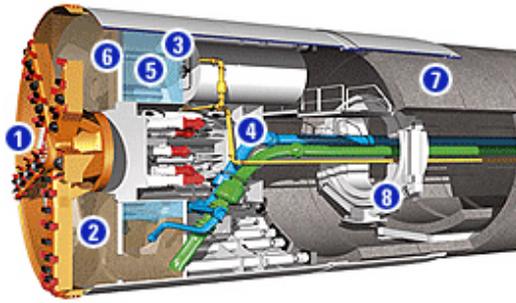
When boring in stable rock an EPB TBM can operate in open mode, although its performance is limited by the lower cutterhead revolution speed and especially screw conveyor wear is quite high. When boring in close mode through unstable and weak rock, by utilizing foams and other additives, a properly designed EPB TBM can apply a pressure to the face, stabilize it and control the ground water up to a pressure of 3-4 bars (depending on the capacity to create a "paste" with very low permeability in order to dissipate the pressure along the screw conveyor). Above these pressures the EPB operation become very problematic. Water and fines flows through the screw in an un-controlled manner (without dissipating pressure). Consequently inside the excavation chamber boulders and larger chips of rocks tends to accumulate and block the cutterhead rotation and shield advance.

EPB TBMs have a long single shield and their capacity of overcutting is limited. Their shield is more easily stuck in convergent rock than the ones of DS TBMs.

Experience say that in hard rock conditions, the operational principle of the EPB cannot be reached in certain hydrogeological conditions due to the follows: 1) Not effective counterbalance pressure in the excavation chamber/Cutterhead to sustain the front of excavation; 2) Impossibility to obtain a reduction of the water pressure from the front of excavation to the discharging point of the screw conveyor and consequently to seal the water out of the tunnel.

### **3.5. Slurry Shield TBMs**

Originally developed for non cohesive soils, in the latest years application of slurry shield TBMs has been widely expanded. These TBM type, use a bentonite suspension to pressurize the excavation chamber and stabilize the front. As in EPB TBMs, cutterhead can rotate both ways. Cutting wheel with low opening ratio degree shall be preferred as they allow a higher number of cutting tools to advance faster in hard rock. A close slurry circuit is employed as spoil removal system and pumps the excavated material out of the tunnel to a slurry treatment plant that provides the separation of the excavated material from the slurry mixture. Conventional Slurry TBMs and Mixshield (or Hydroshield) TBMs, which use an automatic controlled air bubble to control the pressure), can excavate in close mode in heterogeneous formation with water inflow at pressure higher than 15bar. At low water pressure, they can manage potentially high groundwater inflow with no significant effects on the production. Furthermore, the same slurry pumping system can be used for water evacuation while bentonite lubrication has a cooling effect on cutters consumption. The closed muck removal system, ensure the cleanliness of the tunnel, the dust absence, and improve the safety in case of tunneling in gassy areas.



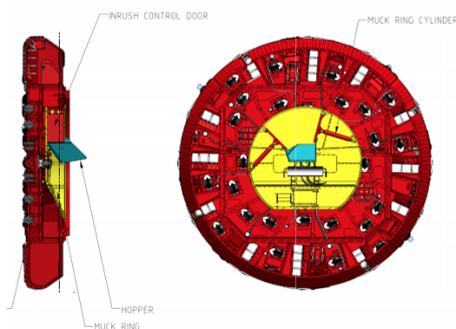
**Figure 6.** Mixed Shield TBM 1--Cutterhead; 2-Excavation Chamber; 3-Pressure Bulkhead; 4-Feed Line; 5-Air Bubble; 6-Submerged Wall; 7-Segment; 8- Erector

Slurry TBMs including the auxiliary equipment require an overall higher investment than EPBs, a large area available for the slurry treatment on site, and high power consumption. In case no treatment of the ground is applied, precast lining shall be dimensioned to bear the loads accordingly.

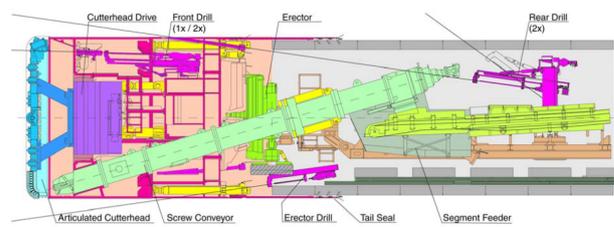
### 3.6. Hybrid TBMs

Hybrid TBMs include features that are typical of more than one conventional TBM type. In this chapter will be briefly analyzed the case of the Vishnugad Pipalkoti TBM (hybrid between a DS and an EPB TBM) and the case of the Arroweld tunnel project TBMs (hybrid between a SS TBM and an EPB). Both are open type TBMs that cannot excavate in close mode but in a “semi-EPB” mode.

The TBM for Vishnugad Pipalkoti Project (India), designed jointly by SELI Overseas with Terratec and Mitsubishi, is provided with a new telescopic shield suitable for TBM operation in DS mode even in unstable and ravelling ground, with very short shields for containing total TBM length similar to the one of a SS TBM, conical shield design, extended overcutting capacity, possibility to drill/grout and insert piles to pre-treat/stabilize the ground at the face, very high main and auxiliary thrust, very high EPB like cutterhead torque capacity, capacity to work in SS mode when the required by the geology with a soil conditioning system and is provided of a high pressure water spray line installed in the center of the cutterhead to avoid material clogging in this critical area. In addition a “flood door” system has been installed on the bulkhead of the TBM. This system regulates the flow of the muck&water to the conveyor and eventually seals out the excavation chamber, simulating almost an EPB advance mode; it will be utilized when boring in special ground conditions to limit the face instability and prevent the flooding of the TBM and of the tunnel.



**Figure 7.** Muck flow control doors in Vishnugad TBM



**Figure 8.** Arrowhead TBM scheme

In Arrowhead Project in San Bernardino (USA), difficult hard rock ground conditions with a potential for high groundwater inflows, high hydrostatic pressures and fractured and faulted rock mass were expected. Two Hard Rock SS TBM manufactured by Herrenknecht with mucking by a screw conveyor and specially equipped extensive pre-excitation grouting facilities have been employed. In order to cope with the heterogeneous ground conditions, such TBMs have been operated in open mode mucking out by a screw conveyor or in standstill mode applying an extensive ground treatment in very poor rock conditions. Cutterhead rotation for excavation was possible in one direction only. Cutterhead was closed type and equipped with cutters. High water inflow have been managed by a dedicated pumping system.

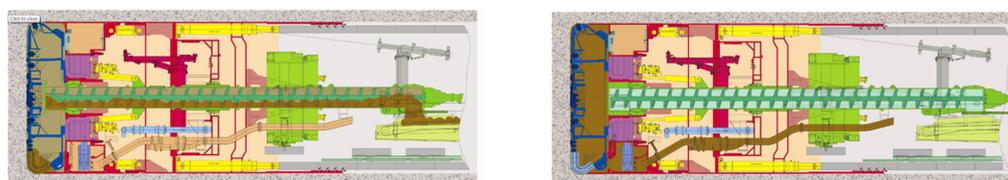
### 3.7. Convertible TBMs

Convertible / Dual Modes TBMs are machines that can switch from one mode of excavation to another one. We will refer to convertible TBMs when the modification requires the replacement of some major component, while to Dual Mode TBMs when there are no major modifications required as they are already provided with features “ready to use” of 2 or more TBM type and are required mainly changes on the configuration and loading system of the cutterhead. Switching mode in Convertible TBMs takes usually 1-2 weeks, while it takes 2-3 days in Dual Mode.

While convertible are more appropriated when two different rock mass sections are clearly identified and they are located ideally at the start or at the end of the drive, with dual mode TBMs rock sections are usually expected to change more frequently.

Among the experiences with Convertible TBMs are included conversions from DS to EPB – see Beles Headrace tunnel SELI TBM where the muck conveyor could be replaced with a screw conveyor and was provided with torque capacity activated by a simple modification – or Eppenbergh Herrenknecht TBM where conversion from SS TBM to Slurry type was requiring also the replacement of the continuous tunnel belt conveyor to a slurry muck system and the installation of a Slurry Treatment Plant out of the tunnel.

An interesting case is the one of Lake Mead project in Las Vegas, where the dual mode Herrenknecht TBM was designed to operate in hard rock with potential high water inflow under a maximum hydrostatic pressure of 17 bar. The TBM was a Single Shield TBM able to work with a horizontal screw conveyor in open mode or by means of a Slurry circuit in closed mode. Although not initially expected, the TBM has been used mainly in closed mode due to the very critical condition encountered.



**Figure 10.** Lake Mead in Open Mode (Left side) and in Closed Mode (Right side)

## 4. INFLUENCE OF TUNNEL DIAMETER ON THE SELECTION OF THE TYPE OF TBM, OF ITS DESIGN AND PERFORMANCES

While, in general, the hydro-geology and the geotechnical parameters of the rock formations play the most important role for the selection of the most suitable type of TBM, another important parameter driving the TBM selection is the diameter of the tunnel.

Diameter has an important influence on the selection of the TBM. When along the tunnel alignment, the prevailing rock mass quality is poor to very poor also with expected high amount of inrush water, the selection moves to a TBM working in close mode (or able to work in Dual Mode).

When the prevailing rock mass quality is good to fair and stable then for small to medium diameter TBM (4 to 7 meters) in rock tunneling in heterogeneous ground, usually DS TBMs shall be preferred due their flexibility as mentioned in the paragraph 6. SS TBMs for such diameter might suffer of three issues:

- a. Cutterhead cannot be retracted from the front in case of collapses and so it is more difficult to restart the excavation if cutting wheel is blocked. A SS of small/medium diameter requires usually a front articulation for being able to be retracted, but this feature results in longer shields similar to DS TBMs. Furthermore, retraction is limited when compared to than the one of a DS TBM.
- b. Secondly, lack of accesses to the rock (in DS TBMs it is possible through the telescopic shields) do not allow intervention to stabilize, treat or discharge the rock around the shields in case of issues.
- c. Furthermore, with SS TBMs is not possible to implement high conicity to the shields and therefore these machines are more subject to Shield entrapment. This happens especially for small to medium diameters, where ratio TBM length/ Cutterhead diameter, is very significant.

Therefore, DS TBM for medium-small diameter are generally more flexible.

For large diameters instead, usually is preferred a SS TBM to a DS TBM. There are many positive experiences on the Alps with SS TBMs of large diameter (9 to 12m). This is due to the chance to realize a Cutterhead that can be moved vertically and horizontally with respect to the shield. This permits to unblock the Cutterhead in case of unstable front, to better drive the TBM in case of mixed front/low characteristic, and to provide some overcutting moving the Cutterhead vertically to the top reducing the low conicity shields issues. Furthermore on such diameters the advantages of DS TBMs in terms of rock treatment are limited since it is difficult to treat the rock through the shields. The enhanced simplicity in the Design and functioning of the SS TBMs on these diameters make this machine easier and therefore reduces the minor productivity due to alternate excavation and lining installation. In addition, the assembly, starting and disassembly time consuming of a single shield are lower than the ones of a DS TBM. In terms of costs, the SS TBMs, being simpler, require a less investment.

Often, even when the general rock mass quality does not strictly requires close mode TBM, diameters under the 4m tend to compromise the characteristics of the EPB TBMs, and central screw conveyors are generally adopted. For Close mode application, the use of central screw is often a compromise that does not allow a proper EPB operation and will cause segregation muck, with boulders and larger chips accumulating in the lower portion of the excavation chamber. Accessibility to the front is also often reduced requiring longer procedure and additional safety devices and procedures to access to front of excavation for maintenance purpose and other intervention into and from the Cutterhead.

In case of need, evacuation of the water can apply only through the screw conveyor since the drainage holes provided for in the lower half of the front shield will be clogged, almost immediately, by muck debris and stuck mud. This will make the mucking out and the control of water very problematic when a low permeable "paste" cannot be created into the Cutterhead and along the screw conveyor. The quite long Front Shield and thus the long distance of the front articulation from

the face, may create steering problems in soft rock/ground due to the heavy Front Shield and Cutterhead. Long shields will be stuck in rapidly convergent ground formation, the unidirectional rotation of the Cutterhead will make difficult to control the torque and shield roll

For small diameters (up to 5-6m), Dual Mode TBMs also are affected by the limited spaces, requiring compromises on the technical choices. This could result in problematic operation in both modes, problem of accessibility to the face, steering and torque control problems, water drainage problems, long stand by times to change configuration, low advance rate even in normal conditions. The above without providing any real advantage in term of capacity to face the extreme conditions expected along this tunnel.

For Diameter above 6m, Dual Mode TBM applications are more suitable when, clearly, the geology presents heterogeneous lithology. Within such cases, the tunnel alignment develops along hard rock formation stretches and very poor rock formation or loose soil stretches with similar extensions.

More frequent in mountain tunneling are the situations where, within hard rock formations, only limited stretches have high tectonic stresses with faults. In these cases, hard rock TBMs (DS or SS for higher Diameters) are in any case preferable mitigating the risks of fault zones crossing through a systematic application of ahead investigation and pre-excavation grouting application.

## 5. INTERACTION WITH DIFFERENT TYPE OF TBMS AND OPERATIONAL MODE

Interaction between TBM and geology is heavily depending on the features of the machines, especially for the Hybrid and Convertible due to their specific variable nature. In the following table however we try to assign a general rating for the analyzed TBM types interacting with different ground conditions in mountain tunneling.

	<b>OPEN GRIPPER TBM</b>	<b>SINGLE SHIELD TBM</b>	<b>DOUBLE SHIELD TBM</b>	<b>EPB TBM</b>	<b>SLURRY TBM</b>	<b>HYBRID TBM</b>	<b>CONV. TBM</b>
<b>EXCAVATION MODES</b>	OPEN	OPEN	OPEN	OPEN / CLOSE	CLOSE	SEMI EPB	OPEN / CLOSE
<b>ADVANCE RATE IN VERY HARD ROCK</b>	++	0	+	--	-	+	AS PER MODE
<b>ADVANCE RATE IN GOOD ROCK</b>	+	+	++	-	0	+	AS PER MODE
<b>ADVANCE RATE IN POOR ROCK</b>	--	0	0	+	++	0	AS PER MODE
<b>FINAL MUCK DISPOSAL COST</b>	++	++	++	-	+	+	AS PER MODE
<b>EQUIPMENT WEAR</b>	++	++	++	- IN OPEN MODE	0	+	AS PER MODE
<b>FACE ACCESSIBILITY FOR MAINTEN./INTERVENT.</b>	++	+	++	0	0	+	AS PER MODE

<b>HIGH GROUNDWATER PRESSURE AND FLOW</b>	--	-	-	-	++	+	AS PER MODE
<b>UNSTABLE FACE- LOW WATER PRESSURE</b>	--	0	0	++	++	+	AS PER MODE
<b>UNSTABLE FACE- HIGH WATER PRESSURE</b>	--	--	--	--	++	+	AS PER MODE
<b>CONVERGENCY OR SQUEEZING GROUND</b>	++	-	+	--	--	VARIABLE ON CASES	AS PER MODE
<b>BOULDERS</b>	++	++	++	--	-	+	AS PER MODE

**Table 1.** Interaction of TBM types with different rock conditions

## 6. SPECIAL MEASURES TO COMPLEMENT TBMS CAPABILITY TO FACE ADVERSE GEOLOGIES

In order to face difficult geologies, TBMs shall be capable to: A. Recognize in advance a potential geology which may cause a TBM disruption/stoppage; B. Pre-treat the Rock Mass in order to improve the geotechnical and hydrological conditions; C. Drain high water inflows.

Therefore, independently from the type of TBM, the machine shall be equipped with:

- A systematic investigation with probe drill
- A large number of holes in the shield to allow the execution of "micro piles of consolidation" very close together and effective with limited inclination for ground treatment
- Additional holes in the shield with higher inclination (15°-20°) having the scope of water drainage
- Possibility to execute drill-holes also through the TBM Cutterhead and within the tunnel cross section
- Grout plant for the application of pre-excavation grouting
- Optimized dewatering system integrated with the TBM and with high capacity pumps all along the tunnel.

## 7. ACTUAL LIMITATIONS OF THE TBM TECHNOLOGY AND NEW DEVELOPMENTS

There is no any TBM kind that can cope with all the variable and extreme severe conditions of poor rock/large water inflow in mountain tunneling. The direction of TBM technology anyway is going towards always more hybrid, convertible and dual mode solution, although sometimes the unconditioned research of theoretical universality to all rock conditions results in reduced simplicity. Having more features to enhance the theoretical flexibility results in a real less effective solutions.

Improvement in the geological forecast is essential in order to reduce the risk of TBM blockage or performance reduction. Steps in this direction have been taken, but require additional improvements in terms of details and reliability.

## 8. CONCLUSIONS

The selection of the most suitable TBM for mountain tunneling shall be the result of a logical process based on geology review, risk analysis for the excavation, capability to investigate and treat the ground, performance (including time and cost for set up, start, assembly and disassembly), quality of the tunnel in terms of final lining and operation. Once the selection is done, the TBM design shall be deeply evaluated in the in the concept, specification and details as this will make a project successful or not in conjunction with the contractor experience. The TBM concept and detail design cannot be left to the TBM supplier only, who rarely has real direct experience in operating TBMs in difficult geologies, but the Specialized Contractor shall contribute and cooperate with the TBM manufacturer providing its experience to the TBM characteristics and features to overcome also the worst conditions.

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