TBM bored long rock tunnels

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TBM DEVELOPMENT

The history of rock TBMs began and developed with the history of long tunnels, starting from the beginning of the XIXth century, when the development of the industrial civilisation led to the development and the acceleration of ground transport of goods and people by rail (Parker 1999). It was therefore necessary to build new and more convenient transport routes: in Europe the crossing of the Alpine mountain range was the first obstacle to be overcome. This became possible thanks to the construction of long tunnels: the first was that of the Mount Cenis railway tunnel (also known as the Frejus tunnel), which is 12.233m long and was built between 1857 and 1871, and for which the Belgian engineer Henry Maus, specifically entrusted by the government of the Sardinian-Piedmontese Reign, in 1848 planned, built and experimented the first rock-tunnelling machine. The machine was never actually used for the construction of the tunnel (Innaurato 1968). During the period 1846-1930, close to 100 rock or hard-ground tunnelling machines of various types were designed and patented, but the actual machines did not, in many cases, reach the light of day. Many of the ingenious devices and/or engineering principles designed or attempted by those early engineers have either been ignored or forgotten. Others can be seen incorporated in the modern tunnelling machines of today.

By the end of the 1920s, after the repeated failures which had attended the introduction of most rock-tunnelling machines, interest in their development tended to wane. In 1952-53 period, the American company, James S. Robbins and Associates, designed and manufactured the "Mittry Mole" (7.8m diameter, 149kW), which opened the story of modern rock TBMs (Stack 1982). Rapid developments in technology permitted TBMs to overcome hard, abrasive rock. They began to extend their range into harder and harder rock and to allow significantly increased penetration rates as time went on.

This improved technology has permitted some impressive development of TBMs. This includes increasing penetration rates in harder rock and at larger diameters. It also includes rapid advancement of methodology and of disc cutter and bearing-seal technology. Penetration rates have increased dramatically while cutter costs have continued to decrease. Hard rock machines have become increasingly reliable in stronger and more abrasive rock. Moreover, machine availability is increasing, allowing overall advance rates to increase.

The Channel Tunnel spawned a considerable development of TBMs and exalted the benefits of a job-site organization.

TBM CLASSIFICATION

Right from the beginning of its earliest applications, the technology of mechanised full-face tunnel excavation has always had to face the limits imposed by the local geology, the economic challenges and schedule competitions of the drill and blast technique and other so called traditional excavation methods.

The development of TBMs has progressed in two directions: • the boring of tunnels in massive, hard and abrasive rock, • the boring of tunnels in stable, competent rock as well as in ground so unstable that the tunnel has to be lined concurrently to the excavation.

The practically infinite number of combinations of rock, soil and environmental conditions which may be encountered during tunnel excavation has provoked a great difference in the types and characteristics of the available TBMs (Pelizza 1998). TBMs have, for some time now, been divided into the following two main categories: • TBMs for tunnel excavation in rock formations: usually used to bore long tunnels in rock of medium to high strength with moderate to large overburden and in good stability condition. The basic problem faced by this type of machine is that of how to break down the rock, • TBMs for tunnelling in so-called loose ground: normally used to excavate tunnels of limited length in basically homogeneous, loose ground and under a groundwater table of limited pressure. The basic problem faced by this kind of machine is that of the stability of the cavity and of the excavation face.

There are many different schemes for the classification of tunnelling machines throughout the world (DAUB 1997) and these depend on the purpose of the classification. The AITES-ITA working group No. 14 (Mechanisation of excavation) is currently working on the definition of an internationally acceptable classification of TBMs with the purpose of also establishing a univocal terminology set and "guidelines" for the optimum choice of the machine. Rock tunnelling machines can be grouped into three main categories: Unshielded TBM, Single Shielded TBM and

Double Shielded TBM, which is the way of creating new types of TBMs that are suitable for application over a wider range of geological conditions, even though the distinction between TBMs for rock and TBMs for loose ground remains.

In the above classifications, neither the reaming boring machines (Da Vià, 1992) nor the raise borers are considered because these machines are of special or limited use.

From the view point of TBM dimensioning, it is necessary to point out that, although today TBMs of 14 meters in excavation diameter have been constructed, it is always a good idea to try to limit the maximum dimension of the tunnel and therefore that of the TBM.

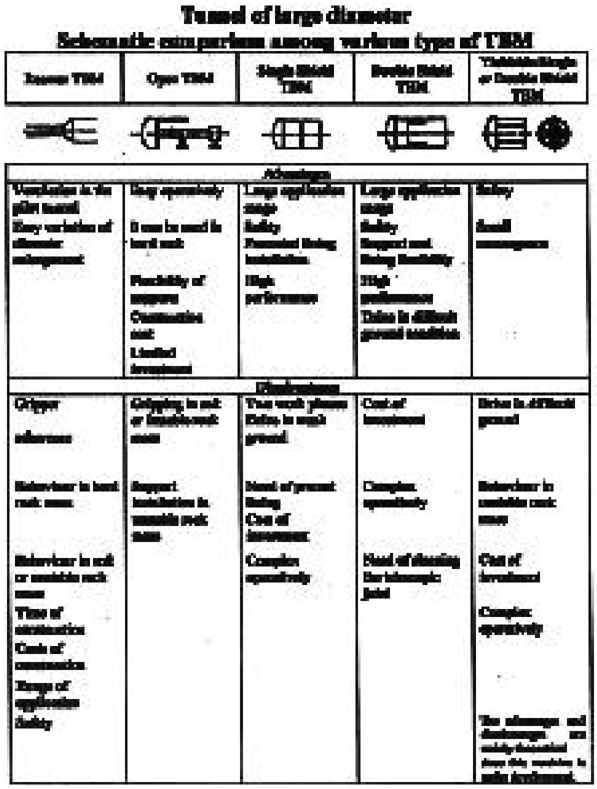
As may easily be perceived, the reasons for limiting the diameter are:

• the potential of TBM in hard rock decreases with increasing diameter (Kovari, 1993; Bruland, 1998);

• there are also technological limits in the maximum dimensions of some major components of for example, the bearing and the head;

• the intensities of both the instability phenomena and the convergence also increases with increasing diameter of excavation (Tseng, 1998).

There already exists a positive and consolidated experience in the use of TBMs in rocks of different quality and strength up to 12 to 12.5 m of excavation diameter.



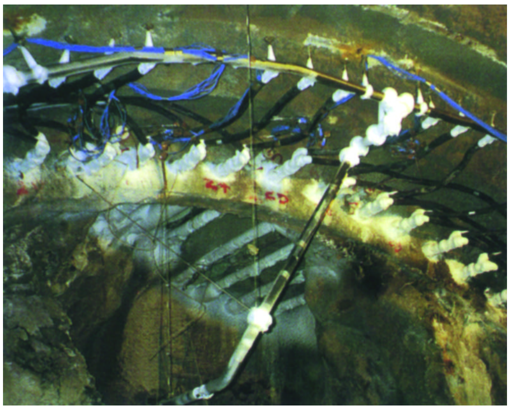
Tunnel of large diameter
Schematic comparison among various type of TBM

Reamer TBM	Open TBM	Single Shield TBM	Double Shield TBM	Telescopic Single or Double Shield TBM
Advantages				
Ventilation in the pilot tunnel Easy variation of diameter enlargement	Easy operatively It can be used in hard rock Flexibility of supports Construction cost Limited investment	Large application range Safety Prefabricated lining installation High performance	Large application range Safety Support and lining flexibility High performance Delay in difficult ground condition	Safety Small convergence
Disadvantages				
Gripper adherence Behaviour in hard rock mass Behaviour in soft or unstable rock mass Time of construction Costs of construction Range of application Safety	Gripping in soft or fractured rock mass Support installation in unstable rock mass	Two work phases Delay in weak ground Need of precast lining Cost of investment Complex operatively	Cost of investment Complex operatively Need of cleaning the telescopic joint	Delay in difficult ground Behaviour in unstable rock mass Cost of investment Complex operatively The advantages and disadvantages are mainly theoretical since this machine is under development.

Beyond 13.5 to 14 m of excavation diameter, the technology today is probably not up to the level of guaranteeing satisfactory performance of TBMs in hard rocks.

The designers should take into account these limits during the phase of tunnel design, making use of the advantages offered by, whenever possible, the reduced sections of the tunnel and, perhaps, even the possibility of having more tunnels running in parallel.

This is particularly true for motorway tunnels where in some cases it is preferable to make triple tunnels each with two lanes for the traffic flow rather than twin tunnels each with three lanes. In the case of railway tunnels, it is better to have two relatively small, single-track tunnels, rather than a large, double-track tunnel.



A great help in the use of TBMs could possibly be acquired through the standardization of the section types of road, motorway, and railway tunnels; this could favour the re-use of TBMs obtaining, at the same time, a constancy in the typology and quality of homogeneous construction works, in addition to gaining considerable advantages in construction times and costs.

As previously mentioned, the value of the TBM, in terms of direct project costs, is relatively insignificant. Failure to achieve the desired results and maintain the schedule, however, will significantly affect the project. From the outset it is thus important to adopt an approach of utilizing the best possible equipment as far as all the aspects pertaining to the TBM and the supporting services are concerned.

Generally speaking, the most reliable machines are the simple ones as they have the least amount of equipment that can break down.

The TBM that is designed to cover all eventualities has, too frequently in the past, tended to be problematic in service and produce performances below expectations.

TBM APPLICATION LIMITS

It is possible to imagine a limiting situation for a TBM where, under given geological conditions, the TBM cannot work in the way for which it was designed and manufactured. For this reason advancement with the TBM can be significantly slowed down or even stopped. Simply speaking, the actual tunnelling conditions encountered are difficult in the sense that the ground does not behave according to expectations.

For each limiting situation, it is possible to introduce special interventions to overcome the problem.

A geological situation cannot be considered to be limiting in an absolute sense but rather only in relation to the type of TBM that is used, its design, any special characteristics and any possible operating errors.

A geological situation only becomes limiting when it is greater than a certain dimension, or when the connected problems are greater than a certain level of severity or due to a combination of events, each of which alone is not critical.

The relatively more important or frequent limiting conditions are: boreability limits (Bruland 1998), instability of the excavation walls, instability of the excavation face including the stability of the open span between the face and the foremost possible area of rock protection, crossing fault zones, tunnels in squeezing clazey rock (Steiner 1996; Vigl 1997; Lombardi 1997), and other particular situations such as clayey soil,important inflows of water, gas, rock and water at high temperatures, and karstic cavities.

Given that there does not exist a TBM that is always capable of advancing, whaterver the geological situation is, it is also true that the overall results of a project depends very much on: • the type of TBM used, and • the design and special construction characteristics of the used TBM. In fact, it is not enough to just order a particular type of TBM from a qualified manufacturer. It is instead necessary for the destined user, that is, the Contractor to continuously collaborate and control all the design and construction details of the TBM. This is particularly true as there are still no “Accepted Standards” for the design and construction of a particular type of TBM, and each TBM that is made is a prototype, each one being different from the other as: • the design and manufacturing of TBMs is a continuous, technological progress (innovation),• its tunnelling project has own characteristics, and • each specialised contractor has his own traditions and convictions.

In this sense, the more correct procedure today is to execute, in parallel, the design of the tunnel and the design of the TBM. On the basis of the above considerations and recent and past experiences, it is possible to ascertain the following points regarding the selection of the type of TBM (some of which are obvious): • shielded TBMs have a wider range of application than the open ones, • this difference in the range of application increases with increasing diameter of excavation, • open TBMs with a double system of grippers are more sensitive to unstable grounds than those with only a single system of grippers, • the wider or narrower range of application of a monoshield TBM, compared to that of a double shield TBM, depend very much on the design and dimensioning of the TBMs themselves and on the type of limiting situations they have to face, rather than on the type of the TBM, • the choice between a monoshield and a double shield also depends on the design of the tunnel section type and whether it is necessary to install precast lining along the entire lenght of the tunnel to be constructed.

However, it should be recalled that in a tunnelling project there are not only technical problems to resolve, but also: • there today exists some types of TBMs that can greatly reduce the number of geological situations which cause important advancement problems, if these types of TBMs are correctly designed and utilized, • there still exists some limiting situations which can only be overcome through special interventions with unavoidable consequences on the construction times and costs of the project, • the use of a Mixed Shield TBMs is not the solution to overcome the limits of TBM application in rock formations, except for in some very particular cases; in this area there is still however a great possibility for further development in the design of TBMs for rock and in the definition of special interventions for application to particular situations, • the importance of the specializations of the contractor and, above all, the personnel director and technical staff on the site, is often forgotten, while in reality it plays a primary role in the functioning of a TBM, particularly under limiting conditions, • the major times and costs involved in the overcoming of a limiting situation in a tunnelling project acquired through competitive bidding, should be mainly supported by the Client who should take into account adequate margins in the programming and budgeting of the project in difficult ground conditions, when limiting situations exceed the predicted “geo” conditions.

CONCLUSION

Mechanised excavation using TBMs is increasingly becoming a branch of industrial engineering and it should be dealt with as such. However, it is true that since rock formations in which tunnels are constructed are not very homogeneous and their behaviour is not always very predictable, the capacities of the machines always need to be supplemented by human experience and by manís ability to interpret situations and hence adjust the use of technical equipment to the situation at hand. The technically universal TBM is a reality today which needs to be nurtured and improved. As of now its potential is such that its use is more secure than traditional methods, in most settings. Unfortunately, in most of the projects being launched for the next few years, the drive towards innovation is curbed by the cautious attitude of the designers, the contractors and the clients who, impoverished in terms of resources as a result of the crisis in this sector, do not have either the courage nor the willingness to test out new technological solutions. This is rather unfortunate as the funds that the State will be investing in such works could and should contribute to the technological innovation of the countries as well as to the implementation of the required infrastructures. Long tunnels at great depth will be the main challenge of the near future (Hartley 1996). The use of rock TBMs is imperative to reduce excavation time. The interest in the full-face boring machine is great because of the advantages it offers: the work site has better safety conditions; work is lighter for the workers; “true” miners are no longer required; the “tunnel”, as an industrial product, is of better quality; the rates of performance, in terms of excavated tunnel, is high; construction times and costs are (or should be) guaranteed. The main problem for long and deep tunnels is that of the application of TBMs under difficult geotechnical conditions. This demanding subject is part of the work programme of the new ITA Working Group No.17 “Long Tunnels at Great Depth” which will begin in Oslo at the annual meeting connected to the 25th ITA General Assembly.