

오늘날의 고성능 TBM과 선진 장비조달 방안

지왕률

Modern High-Power TBM with Advanced Procurement System

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Abstract Recently, the application of High-Power mechanized tunnelling technology has been expended around the world. Especially, High-power Modern TBM machines are used in a successful results. Essential for the great success of this modern TBM in difficult rock conditions are based on the development of machine power, suitable better cutter developments, and also developed assesment technology regards on the extensive site investigations. OPP (Owner Procurement Process) system is a proven alternative contract delivery method that is potentially applicable to many tunnel projects. Using the OPP, the owner specifies and procures the TBMs and tunnel lining in advance of the tunnel contract procurement and provides TBM to a tunnel contractor with a goals of reducing project risks and accelerating project schedule. Depending on the blasting vibrations and noises, mechanized tunnelling will be more important particularly in city areas.

Key words Modern High Power TBM, Procurement, OPP

초록 세계적으로 Modern High-Power TBM을 이용한 터널공사가 점점 많아지고 있다. 특히 오늘날의 고성능 TBM의 개발로 많은 터널공사에서 성공적인 결과를 가져왔으며, TBM 동력의 향상과 커터 등 면판설계 기술의 발달, 및 TBM 굴진을 예측 소프트 웨어의 사용 등으로 터널공사의 자동화, 기계화가 이뤄 졌으며, TBM 장비조달은 OPP 방식을 이용한 발주자 직접 구매 방식이 TBM 선진국에서 효과적으로 사용되고 있다. 최근 많은 나라에서 환경 민원 등의 문제로 인해 도심지의 발파공법사용이 금지되어 TBM을 이용한 터널의 기계화 시공이 세계적인 추세이다.

핵심어 Modern High-Power TBM, TBM 장비조달

1. INTRODUCTION

Normally, it can be classified the TBM projects units with Large scaled TBM and Micro TBM, and the Large diameter TBMs are used major on the Traffic tunnels including roadway, railway, metro projects, and waterway, sewage, multi purpose tunnel like SMART tunnels in Kuala Lumpur, Malaysia (Fig. 1)

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Fig. 1. A pose of the modern High-Power TBM at the starting stage



Fig. 2. World's large scale soft-ground TBM for Xangxing tunnel, Shanghai, China

2. WORLDWIDE HIGH-POWER TBM APPLICATION

2.1 Soft-ground modern TBM application cases

Leading TBM manufacturer Herrenknecht has the record for the world's largest Soft-ground TBM from year 2006, largest EPB Shielded TBM with a diameter of 15.20 m of long motorway tube in Madrid, Spain. Few years ago, world's largest TBM, diameter 15.43 m twin roadway tunnels in Xangxing tunnel projects (Fig. 2), which line up to start boring two 7.4 km long motorway below Yangtze river in Shanghai, China. This project has completed the tunnelling one year earlier than the original schedule September 2008.

2.2 Hard-rock Modern TBM application cases

The longest hard rock tunnel project in the world are being built with German machines in St. Gotthard tunnel in Switzerland with diameter 10 m (Fig. 3). Gripper type TBM has been boring and supporting the Gotthard Base railway tunnel at 57 km twin tunnel, and trains are due to operate rolling in 2016. The largest scaled Hard rock TBM was recorded from the Niagara fall waterway project with 14.40 m diameter by Robbins "Big Becky" USA. The Guadarrama tunnels are the most important work of the new Spanish High Speed Railway network. This Tunnel work consists of a base tunnel of length 28.4 km whose route crosses underneath the mountain range of Sistema Central at a maximum elevation 1200 m a sea level at Penalara, with a maximum overburden 992 m. Guadarrama tunnel



Fig. 3. High-Power TBM at the Alpstransit jobsite

project is the first longest tunnel excavated only by TBM in the world, and they completed the 28.4 km rail tunnel in a 33 months which shows TBM could be an easy method to overcome the critical path of the long tunnel projects.

2.3 Development of Convertible modern TBM

Modern TBM with convertible mode, that allows for a change of driving mode during tunnel excavation, could be utilized in varying geological and ground water conditions. By site machine modification these types of TBM enable a better adjustment to the geological conditions encountered in the variable tunnel faces. Now the Mixed shield TBM from Herrenknecht can be operated as an EPB Shield TBM, and a Slurry shield TBM as the same time, with supporting of air compressore units (Fig. 4).

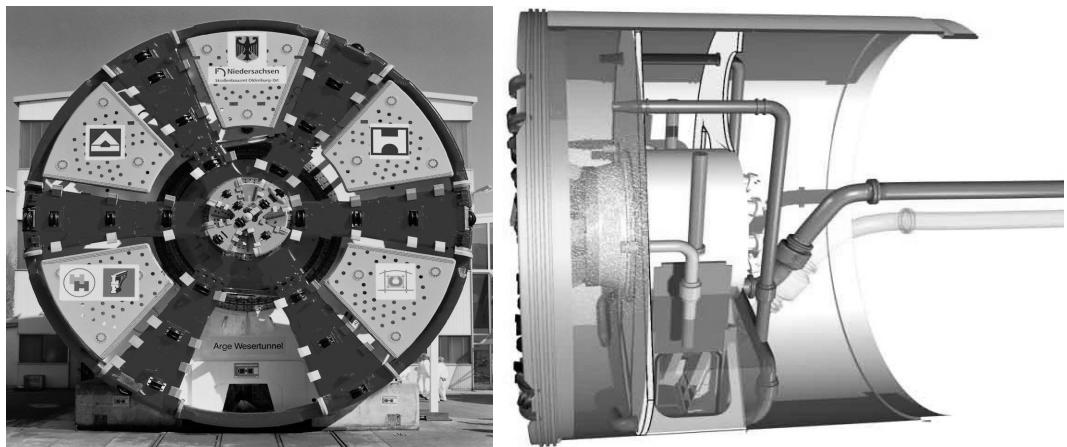


Fig. 4. Mixed shield TBM as a Convertible style machine

Table 1. World records for high speeds tunnel excavation^{3),4)}

DIAMETER	3~4 m	4~5 m	5~6 m	6~7 m	7~8 m	8~9 m	9~10 m	10~11 m	11~12 m
BEST DAY	172 m Robbins Katoomba Australia	128 m Robbins SSC No.4 USA	99 m Robbins Little Calumet USA	14 m Robbins Dallas Metro USA	92 m Robbins Epping Rail Australia	75 m Robbins Channel Tunnel UK	74 m Robbins TARP Chicago USA	48 m Robbins TARP Chicago USA	30 m Herrenknecht Murgenthal Switzerland
BEST WEEK	703 m Robbins Katoomba Australia	477 m Robbins SSC No.4 USA	562 m Robbins Little Calumet USA	500 m Robbins Dallas Metro USA	372 m Robbins TARP Chicago USA	428 m Robbins Channel Tunnel UK	324 m Robbins TARP Chicago USA	185 m Robbins TARP Chicago USA	100 m Robbins Bozberg Switzerland
BEST MONTH	2066 m Robbins Oso USA	1822 m Robbins Yellow River China	2163 m Robbins Little Calumet USA	1690 m Robbins Dallas Metro USA	1482 m Robbins TARP Chicago USA	1719 m Robbins Channel Tunnel UK	982 m wirth Guaderrma Spain	685 m Robbins TARP Chicago USA	385 m Robbins Bozberg Switzerland
MONTHLY AVERAGE FOR PROJECT	1189 m Robbins Katoomba Australia	1352 m Robbins Yellow River China	1095 m Robbins Yindaruin China	1187 m Robbins Dallas Metro USA	770 m Robbins TARP Chicago USA	873 m Robbins Channel Tunnel UK	715 m Robbins TARP Chicago USA	None reported	None reported

2.4 Records of the TBM Performance rate

Four working TBMs with four portals drives for the twin tunnel Guadarrama tunnel in Spain (Fig. 5), have provided the tremendous data for analysis and comparison. Rather than to compete the four TBMs against each other in a sprint to record the high speed tunnel excavation. The TBMs complete the 28.4 km length of 10 m diameter long tunnel in a 33 months, average advance rate around 17 m/day (Table 1). The modern

High-Power TBM, could extremely reduce the construction cost and construction period for the maximize the usage of the tunnels^{1),2)}.

2.5 Modern TBM Procurement System (OPP)⁶⁾

Tunnel constructions continue to expose contracting parties to risks associated with unknown ground conditions and behaviour those often results in contractual claims. The TBM and its suitability have tremendous



Fig. 5. The longest tunnel operated by High-power TBM in Guadarrama, Spain⁵⁾

Table 2. Lists of known projects with owner procured TBMs^{3),4)}

Project	Owner	Location	Year	Use	Ground	Machines	Length
London Water Ring Main	Thames Water Authority	London, UK	1991	Water	Clays, sands, gravels	3 × 2.95 m EPB/Open	33 km
St. Clair River Tunnel	CN North America	Ontario/Michigan	1992	Rail	Soft clay	9.5 m EPB	1.8 km
Sheppard Subway	Toronto Transit Commission	Toronto, Ontario	1996	Subway	Glacial till	2 × 5.9 m EPB	3.9 km each
Rio Subterraneo	Aguas Argentinas	Buenos Aires, Argentina	1995	Water	Soil	2 × 4 m EPB	15.2 km
Changi Metro Line	Land Transport Authority	Singapore	2000	Subway	Weak rock	2 × 6.1 m EPB/Open	3.5 km
Various Sewer Projects	City of Edmonton, Alberta	Edmonton, Alberta	13 machines since 1972	Sewer	Glacial till	12 Open face & EPB (2.4 to 6.7 m)	100 km
Melbourne Rail Loop	Melbourne Underground Rail Loop Authority	Melbourne, Australia	1972	Metro	Weak rock	2 × 6.85 m	4 drives 2800 m each
Nuclear Waste Repository Study	US Department of Energy	Yucca Mountain, Nevada	1994	Nuclear waste	Welded tuff	7.6 m	7.3 km
Lower Kalamazoo Mine	Magna Copper Company	Oracle, Arizona	1993	Mine	Hard rock	4.6 m Open gripper	9.7 km
Stillwater Mine, East Boulder Project	Stillwater Mining Company	Nye, Montana	1996, 1987	Mine Rock	Mine Rock	2 × 4.6 m 1 × 4.1 m	5.6 km each Not known

potential cost and schedule impacts and hence pose a significant risks. Usually machine supply requires in a minimum 10-12 months before the TBM arrives on site. The traditional bidding process provides a relati-

vely short period for bidder to review geotechnical conditions and make vital decisions regarding the features of the TBM.

OPP (Owner Procurement Process) system is a proven

alternative contract delivery method that is potentially applicable to many tunnel projects. Using the OPP, the owner specifies and procures the TBMs and tunnel lining (PC Segment) in advance of the tunnel contract procurement and provides TBM to a tunnel contractor with a goal of reducing project risks and accelerating project schedule. The process was first used in Melbourne, Australia, in the early 1970's and has been used by at least 10 owners worldwide (Table 2).

The OPP process generally involved as follows (Fig. 6), (Table 3).

- * The owner determining the TBM requirements during preliminary design of the main tunnel contract,
- * The TBM manufacturer being selected during final design. Concurrently the owner procures the tunnel lining(PC Segment),
- * Pre-qualified tunnel contractors are included in the process,
- * TBM and lining is supplied to the selected tunnel contractor

2.6 Development of Vertical Boring Machine

Mechanized tunnelling expands its range and field of application with a powerful and accurate shaft sinking project with VSM (Vertical Shaft Sinking Machine). The VSM is designed to master excavations in hard rock formations. The VSM will operate at depths of up to 800 m with 10 m diameter (Fig. 7).

In order to reduce the blasting noise and vibration from the Drill and Blasting shaft sinking method, mechanized shaft sinking system will be optimized for the urban vertical tunnel construction to reduce the endless local claims from the residents⁸⁾.

2.7 Modern TBM Tunnel Construction Management

Tool, Data logger

Modern TBM machine shall be fitted with a Data Logger which shall be linked by the Tunnel Manager to a colorful monitor display in the Engineer's office of the job site. The Data Logger shall display and record information in real time and shall have the facility to store all accumulated data from the tunnel drive and to real and display past data. As a minimum

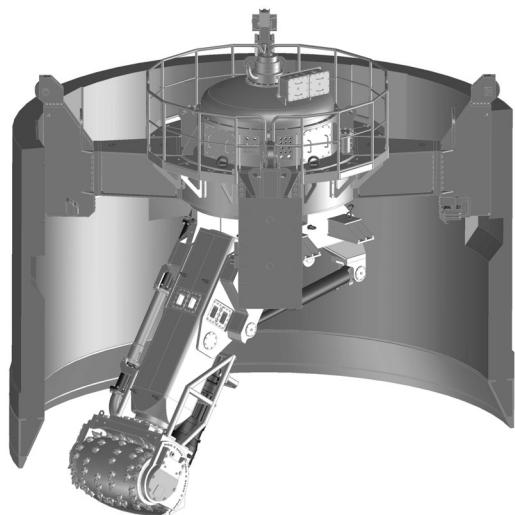
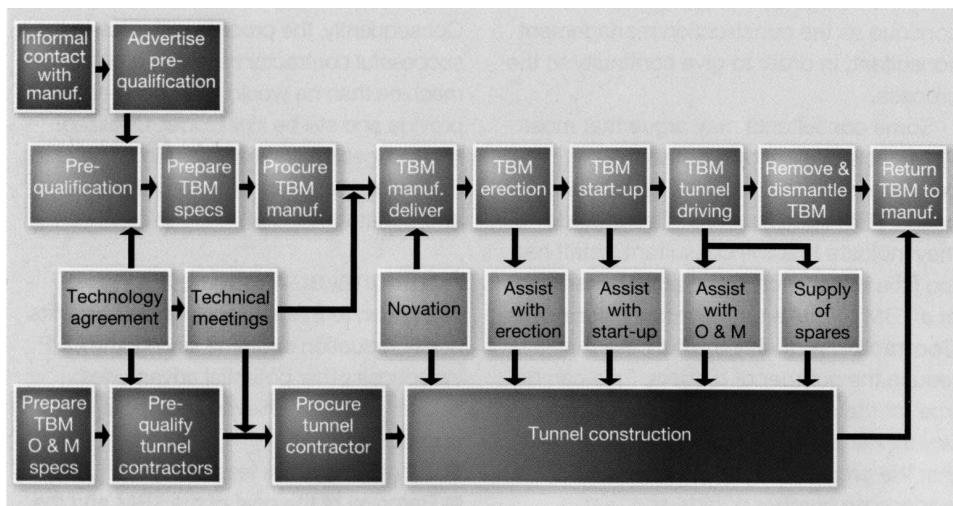


Fig. 7 Shaft building by Mechanized tunnelling in urban hard rocks

Data Logger shall record and report the following information to assess the TBM performance rate on time⁹⁾:

- Start and end time of the excavation stroke
- Stroke number, chainage and guidance system's prediction of the next ten strokes after each build,
- Numbers of thrust cylinders, location and pressures used during the stroke
- Extensometer readings of cylinders at the start and of the stroke
- Articulation cylinder position at the start and the finish of the excavation stroke
- Amount of TBM roll at start and end of the excavation stroke
- Cutting direction, speed, pressure/torque of cutterhead
- Shield position and attitude for each ring
- All earth pressure sensor readings throughout the excavation stroke for cutter chamber and screw
- Volume and pressure of grouting injected per stroke. Pressure shall be measured at the point of injection. Pressure and volume shall be monitored and recorded to an accuracy of not less than two decimal places.
- Volume, pressure, rate of addition, type and location of soil conditioning added per ring and the cumulative amount per shift with the concentration

Fig. 6. Planned operation of the OPP project case^{3),4)}Table 3. An assessment of the advanced TBM procurement^{3),7)}

Party	Advantage	Disadvantage
Melbourne URL Authority	<ul style="list-style-type: none"> - Build up of know-how(system projects) - Specification according to client ‘wants’ - potential early start of tunnelling - Higher certainty on delivery schedule of TBM procurement - Control over TBM costs - Risk transfer to contractor - Economy of scale for multiple TBM procurement - Reduced TBM contingencies in contact price - Longer TBM procurement period - Attraction of smaller less qualified contractors - Centralisation of spare parts 	<ul style="list-style-type: none"> - Early capital investment - Risk on selection of right TBM - Wear and tear risk - Build-up of detailed know how - Client left with TBM or small buy-back value - TBM overspecified - Interface clients/supplier/contractor - Standstill and delay risk - Dependence on consultants - Client left with TBM but no project - Responsible for all TBM related problems - Maintenance/production trade-off by contractor - Marketing efforts of TBM suppliers
Stillwater Mine	<ul style="list-style-type: none"> - Substantial additional efforts - Increased site managements/control function - Build up of expertise/special advisor package 	
London Water Ring Main	<ul style="list-style-type: none"> - No advance financing of investment - Reduce efforts for advanced works - Claim potential when problems with TBM - Typically no TBM ownership after completion 	<ul style="list-style-type: none"> - No utilisation of inventor plant and equipment - Loss of competitive edge - Loss of or reduced influence on configuration - Reduced revenues (Smaller project size) - No direct contact with TBM manufacturer - No/reduced input of experience - Risks for TBM without or limited involvement - Refurbishment risk - No/limited input on work flow on TBM - Contractor’s role reduce for TBM driver
St. Clair River Tunnel	<ul style="list-style-type: none"> - Negotiation with client organisation - Early involvement with client - Bulk procurement - Higher security on payments - Higher level of requirement 	<ul style="list-style-type: none"> - Contact with client/used by contractor - Performance bond requirement

- value. The operation and control of the soil conditioning shall be from within the control cabin.
- Quantity of tail grease consumed per shift
 - Speed and torque of screw conveyor
 - Rate of advance of TBM and stroke average rate of advance
 - Use of copy cutter, amount and location
 - Gas detector sensor readings and alarm activation system
 - Main bearing axial force
 - Main bearing lubrication temperature monitored at exit point if re-circulatory oil, or thermocouple against bearing if grease lubricated
 - Volume and mass of material on the belt or in the slurry line
 - Volume of tail seal lubricant consumed per 24 hours, and
 - Start and finish time of the ring erector operation

Data Logger shall be connected to computer which shall be appropriately configured so that the signals are processed and displayed on monitor in color.

All dataloggers and ancillary equipment shall be fully operational at all times and shall be maintained by the tunnel contractor.

2.8 Present status of Large scaled Modern TBM in Korea

Full face boring of tunnels and raises in the worldwide, However, in Korea, name of TBM projects are minor, especially the traffic tunnel as a large scaled Modern TBM never been to see, never put into operation for the domestic traffic tunnel projects indeed. Marvelous unsolved riddle in Korea just like a heavy industrialized country, the mechanized tunnelling rate is below 1% in traffic tunnel projects, look and compared with the neighbour, China, Japan, Chinese Taipei in year 2012.

What is the major reasons to kill the modern High-Power TBM operation? Korean Tunnelling Society will be restarted to open the virgin TBM market in Korea sooner or later.

3. CONCLUSIONS

The last five years have seen a remarkable increase

in tunnelling projects in both soft ground and hard rock applications in Asia. Part of the increase is a result of recent Research & Development efforts of the European countries to improve Tunnel Boring Machine (TBM) adaptability, capability and reliability. This paper reviewed the latest innovations in the TBM industry and explain in detail the results of these innovations followed by a forecast where the technology with new procurement system, OPP will take the Korea tunnelling industry in the very near future.

Modern tunnelling engineers cannot further improve for human and the environment without technological progress. High-power mechanical tunnelling technology is an excellent example of the way the Korea Tunnelling Society to go for the better future. High quality, high TBM performance, safety, reliability and complicated geological solution by High-power TBM will be the answer for the economical and fast tunnel construction with a new generation tunnelling technology.

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