기술초대석 | 한국지반공학회지 | Vol.24, No.10 | pp.9~22

Mechanical Development for Saving Shield Tunneling Cost

Akira Hatakoshi
Mitsubishi Heavy Industries
(akira1_hatakoshi@kbg.kobe.mhi.co.jp)

장 수 진
고진물산 대표이사
(kojhin@kornet.net)

쉴드터널의 공사비용을 절감하기 위한 방법으로는 굴착연장을 장대화하여 연장대비 장비비용을 절감하는 방법이 있다. 이에 일본의 경우, 장거리 굴착을 위한 쉴드TBM의 개발에 많은 노력을 기울이고 있다. 장대터널공사에서의 쉴드TBM을 이용하는 경우, 굴착공기가 불가피하게 길어지기 때문에 고효율 장대터널용 기술이 요구된다. 이에 본 기사는 상기의 현황에 대해 일본의 쉴드TBM의 개발기술과 적용사례에 대해 나타내었다.

김재영 편집간사 번역(geokimjy@korea.com)

1. FORWORD

Various difficulties have increased in the construction of public underground tunnel structure in the overcrowding urban area, like as the subway, multi-purpose duct and sewerage tunnel, etc. The construction work should be so as not to cause the trouble for crowded people' s life activities on the ground surface, and it is being more difficult to secure the ground surface area for surface occupation of underground structure and the construction site.

The tunneling method with the closed mode type mechanical shield machine such as earth pressure balance (EPB) shield and slurry shield is one of the effective methods that can conquer such difficulties in the soft soil tunneling. Because the shield tunneling method has a characteristic of not disturbing the use of ground surface except the small area of launching and arriving shaft, and additionally, the closed mode type shield tunneling method has the measures and the mechanism for keeping the pressure of tunneling face for preventing excessive flow out of underground water and decreasing the rate of

stress release which cause the earth moving such as the settlements or falling down of the ground surface. Therefore, as shown in Fig. 1-1, most of shield machine type used for the tunnel construction in soft ground in Japan has became closed type in these 20 years.

The machine cost have been increased in the use of these types of machines compared with a conventional open type machine, and the cost occupation rate for shield machine in the total direct construction cost reaches 15 - 20%.

Generally speaking, the total cost of shield tunneling is higher than other tunneling method. So some researches for saving segment cost, shield machine cost and labor fee have been done by project owners of Japan strictly within these 10 years.

For shield machine, the way to minimize the machine power was studied at first, but the effect of cost saving by that way is discovered as a little. And next, the way to use one shield machine to the long distance tunnel excavation and to save the relative cost rate of machine was considered. Additionally, when the excavation length of the tunnel became long, long period should be spent on the construction only by the conventional tunneling technology. Therefore, the needs for the high speed construction technology have also grown up.

Some examples of long tunnel construction can be seen in the past. Especially, the Dover channel crossing railway tunnel, the mechanical tunneling length reaches 49 km in total that connects England and France, is enumerated as the famous one. In that construction, the Japan made shield machines achieved high-speed construction, and it became an example of planning the long distance high speed tunneling in Japan.

In the achievement of the long distance high speed tunneling, the improvement of the durability of the equipments including the shield machine and the

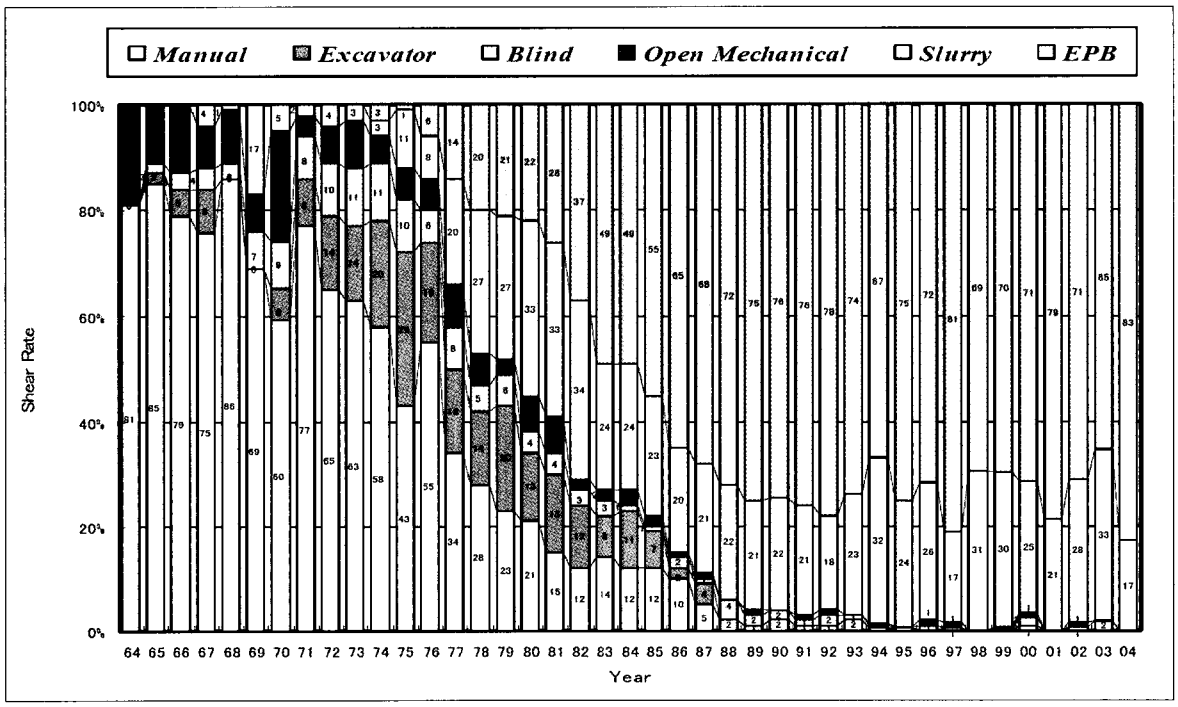

Fig. 1-1 Historical change of shield machine type in Japan

reduction of cycle time are nominated as the subject to be solved. The researches and developments of the solution of these subjects for shield machine have been done up to now through some laboratory tests and some executions in the actual tunnel projects. The Japanese situations of such developments are introduced hereafter.

2. TECHNOLOGY FOR LONG TUNNEL EXCAVATION

2.1 DURABILITY OF SHIELD MACHINE

The closed type shield machine should work in the environment of soil pressure and the underground water pressure, and it should keep the atmospheric pressure environment inside of tunnel. The durability should be considered for the devices equipped on the outside of the machine including the boundary of different environment, because it is difficult (need high cost and long time) to exchange or to repair such kinds of devices. The durability of devices equipped inside machine doesn't become a serious problem.

The element devices for which the durability should be considered seriously are shown in Fig. 2.1-1 as an example of EPB Shield.

(l) Cutter bit

The durability of cutter bits is the biggest subject to achieve the long distance excavation in any geological conditions because they are strongly affected by the nature of soil.

The elements that decide the durability of the cutter bits are the selection of type of cutter bit, the selection of the tools that protects cutter bits from wearing or cracking and the selection of cutter bit tip material.

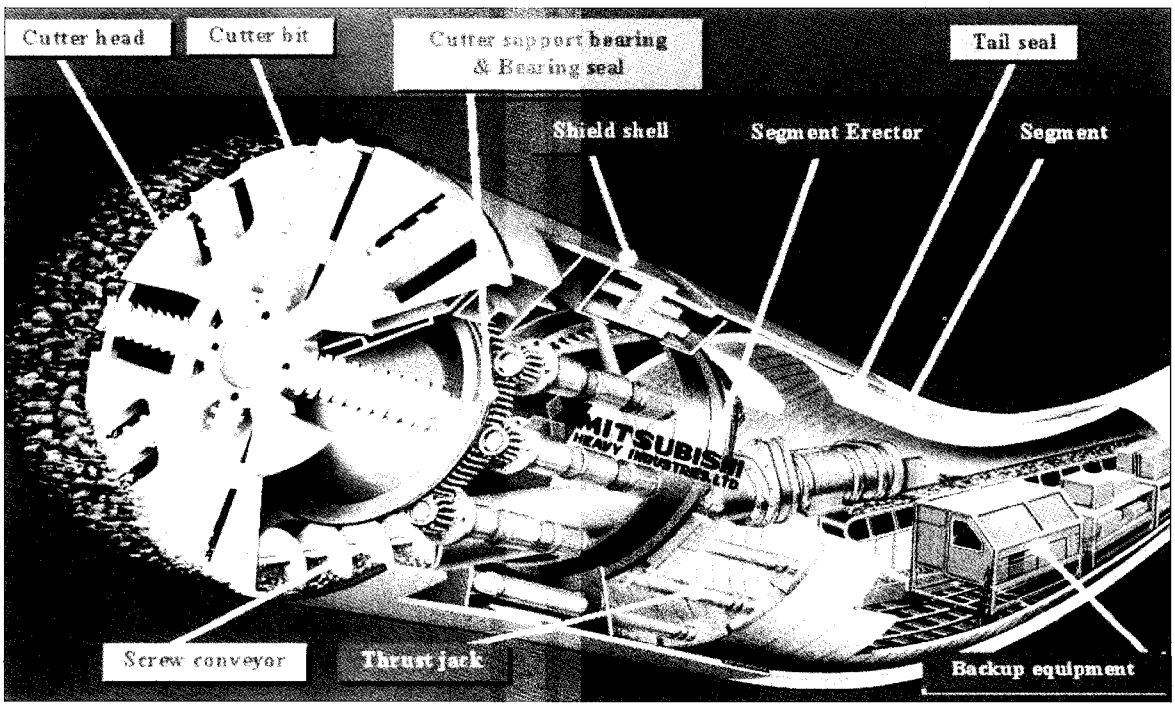

Fig. 2.1-1 Devices of durability required (red letter)

(2) Cutter head

Basically, when the cutter bits were properly arranged and alive, they play the role to protect the cutter head structure. However, it is necessary to install the special cutter head protection bits which have same tip material as the cutter bit tip material for guarding the front side and the outer side of cutter head. And it should be also considered to attach the anti-wearing plate on the suitable position of cutter head according to the soil type.

(3) Tail seal

Now the wire brush type tail seals are installed for most of shield machines. The durability of tail seals cannot be described quantitatively because there is the probability of trouble happening to the tail seals by tunnel alignment, accuracy of the segment assembly, backfilling material and backfilling management etc. The presumption of the tail seal life is very difficult.

Equipment of automatic control device of special material (tail grease) filling between two or more rows of tail seals is effective for keeping the durability of tail seal. However, it is necessary to consider the seal system structure to be able to repair from inside of shield machine for the long distance excavation. The seal structure with temporally emergency seal is effective for this purpose.

(4) Cutter bearing seal

The bearing seal protects the main bearing which supports the cutter head from the infiltration of soil particles and underground water. In the closed type shield machine, the seal material should slide on the steel material for long distance contacting with the pressurized soil particles and water at the forefront. When the main bearing damage was caused by the loss of sealing function of the sealing system, so much cost and time is consumed for repair. So this seal can be said the most important part of the closed type machine and the durability of the part should be certificated strictly.

(5) Cutter bearing

The roller bearing of big diameter is adopted in most of shield cutter bearings now. The method of calculating roller bearing life has been established considering the load conditions (thrust force of the shield, amount of the rotation parts weight, soil and hydraulic pressure, time shearing rate of some cases of loading condition) and the operation conditions (cutting torque of cutter head, cutter rotational speed). It is necessary to design the load capacity of the bearing according to the excavation distance and machine' s working period based on the calculation method.

(6) Soil discharging device

It is necessary to consider the easy maintenance of soil discharging devices together with the improvement of their anti wearing durability against the contact with soils.

The soil discharge of slurry shield is done through pipe line. So the maintenance of the pipe line can be easily only installing any valves on the bulkhead or in the line to dismantle the damaged pipe. For EPB shield, main discharging device is the screw conveyer of a large scale device and the maintenance for the device is more difficult. So it is important to take up some anti wearing measures for screw casing and/or screw blade, using thick and hard steel plate and/or hard coating of steel material surface considering the geological condition. Moreover, to make it detachable from the bulkhead under construction, a shutter like as gate valve should be installed at the inlet of screw conveyor if necessary.

Among these elements, the durability of cutter bits and the cutter bearing sealing system are considered the most important subject, and the Japanese technical development about these parts is described here after.

2.2 DEVELOPMENT OF CUTTER BIT TECHNOLOGY

For improving the durability of cutter bits, there are roughly the following two kinds of technological study or development.

- Study of high anti-wearing property of cutter bit tip material
- Development of replacement mechanism of cutter bits

2.2.1 STUDY OF DURABILITY OF CUTTER BIT TIP MATERIAL

The material of cutter bit tip is a super-hard alloy of tungsten and it is selected among some classes of characteristics. In Japan, characteristics of tungsten alloy are standardized by Japan Industrial Standards (JIS) shown in Tab. 2.2-1, and class E5 is selected for the normal material of cutter bit tip.

Generally speaking, the abrasion resistance of materials is proportional to the material hardness (HV :HRA can be converted to HV), so it is easy to understand that it is effective to use harder tungsten alloy for cutter bit tip material to get higher durability of cutter bit tip.

But the material becomes easy to crack according to the increase of its hardness. The cracking of cutter bit tip occurs mainly by the impact load in the excavation in gravel layer, weathered rock or chemically consolidated soil. Therefore, the study theme of cutter bit tip material is to increase the resistance for cracking while raising the hardness. One of the parameter which shows the resistance for cracking is transverse rupture strength of material.

Study on obtaining the super-hard alloy to which rupture strength is corresponding of E5 and hardness is excessive than E5 was advanced in each place. The cause of the easiness of the tungsten carbide sintering alloy to crack is in the internal structural defects that remain in the metallic organization after the sintering process.

Mitsubishi also executed the experimental study of cutter bit tip material of high durability. The test pieces of new 31 kinds of tungsten alloy were made and their characteristics were checked. To reduce the internal defects, some trials of the adjustment of a cobalt amount (cobalt is the bonding material of tungsten) and the size mixing of particle tungsten powder material have been executed.

Most of the new alloys show higher rupture strength than the regulated level of JIS, but the strength ratios to E5 were below 1.0 shown in Fig. 2.2-1 with red mark. Then next, an improved sintering process was applied to 14 kinds of them and the test results of such 14 kinds are shown also in Fig 2.2-1 with blue mark. The data show the improvement of rapture strength of alloys.

In the new sintering process, alloys were sintered with hot isostatic pressing process (HIP process). This sintering method is the process of sintering the material in the

Tab. 2.2-1 Standard of Tips for Mining Tool

CLASS	HARDNESS H_{RA}	TRANSVERSE RUPTURE STRENGTH N/mm²	COMPONENT %		
			W	Co	C
E1	>90	1177	87-90	4-8	5-6
E2	>89	1373	85-89	5-10	
E3	>88	1569	83-87	7-12	
E4	>87	1667	82-86	8-13	
E5	>86	1961	78-85	9-17	

JIS M 3916

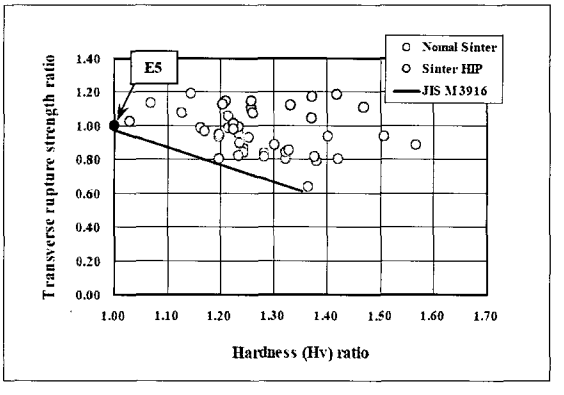

Fig. 2.2-1 Characteristic of new tungsten alloy

atmosphere of pressurized noble gas and it was recognized to be effective measure to improve rupture strength of tungsten alloy of high hard ness.

In the presence, HIP sintered E3 material is widely used for cutter bit tip material of the shield machine for long tunnel or hard soil excavation. The anti-wearing characteristic of HIP sintered E3 material is certified more than 1.5 times of normal E5.

2.2.2 MECHANISM FOR CUTTER BIT REPLACEMENT

Replacement of cutter bits is an effective means to maintain the excavation function of the shield machine through long tunnel excavation. When the replacement is done by worker at the tunnel face, it is necessary to keep the safe working environment in the soft ground with a large quantity of underground water, except in the stable and no water rushing condition like the hard clay layer. For this purpose, an enormous cost and environmental setup period are needed for the chemical injection method, compressed air method, the freezing method or other soil stability improvement methods.

To save such cost and time, various mechanical technologies to replace the cutter bits easily are developed, and some of that have been applied to practical use in present Japan.

(l) Installation of sub cutter bit

Another cutter bits are stored in the cutter head besides the cutter bits that works for initial excavation, and the cutter head is equipped with the device that can take out the stored cutter bits by mechanical movement aiming at cutting face when the initial cutter bits are worn out.

There are two kinds of mechanism as follows.

(a) Pushing out mechanism

Some numbers of sub cutter bits are grouped and supported by the hydraulic jack and they are stored in the cutter head initially. In the replacement operation, the jack is extended by the controller of inside machine, and the stored new cutter bits are pushed out forward.

However, the replacement can be done only one time and there is the limitation of replaceable area depends on the arrangement of the new bits. Fig. 2.2-2 shows the concept of the structure. It is necessary to fix the new bits after pushing out to the final position, and some types of stopping mechanism like a spring lock, a jack operated lock pin, etc. should be installed.

Because of the simple mechanism, this mechanism was applied to some shield machines for long distance excavation.

In a power cable tunnel project in Osaka, 6.5km length tunnel was excavated using 5.8m diameter slurry shield machine with this mechanism shown in Fig.2.2-3. Each one half of the numbers of stored sub cutter bits was replaced at two points of 4.6km and 5.6km.

(b) Cutter spoke rotation mechanism It is the structure that the cutter spokes can be rotated by using hydraulic jacks or motors. The spoke is installed the

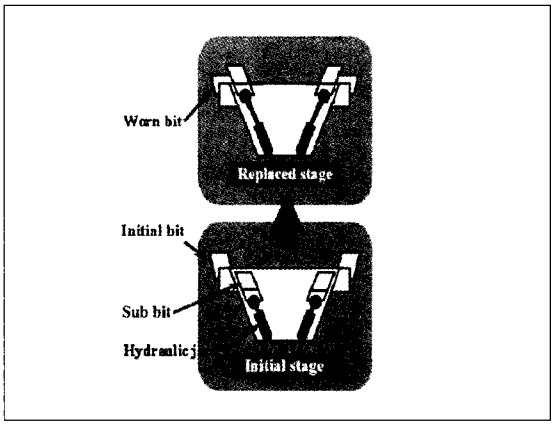

Fig. 2.2-2 Sub bit push out system

cutter bits of multiple rows around the surface as shown in Fig. 2.2-4. The initial cutter bits are set toward to tunneling face and when these are worn out, the spoke is rotated and the new sub cutter bits are put in front of the cutter head.

The replaceable area of cutter bits is comparatively wide but the structure becomes a little bit complex. There is a feature that it differs from the mechanism of pushing out type, there is no remain of the worn out cutter bits on the cutter face.

On the EPB shield machine of 6.2m diameter for the sewerage tunnel construction in Fukuoka, the spoke rotation mechanism with hydraulic motor was installed for partial weathered rock excavation.

Some various rotation mechanisms were already developed and used.

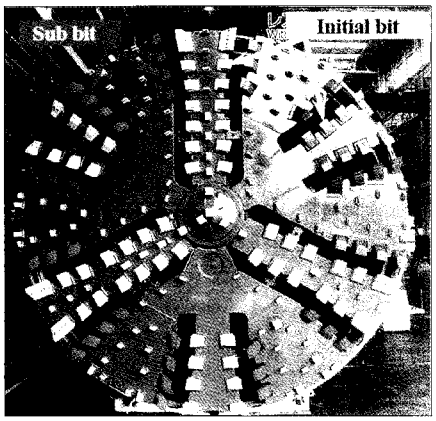

Fig. 2.2-3 Cutter head with push out bit

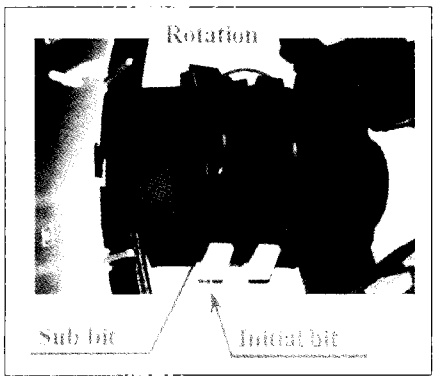

Fig. 2.2-4 Cutter spoke rotation

(2) Cutter driving device turning mechanism

This is a huge scale mechanism for cutter bits replacement. An inner shell that has the partial spherical surface is installed in the main body of the shield machine. The whole cutter driving device is installed in the inner shell and the shell is supported by the structure which is able to turn the shell horizontally. When the initial cutter bits are worn out, after the outer part of the cutter spokes of the cutter head is shrunk and the entire cutter device including cutter head is drawn back in the inner shell, the shell is turned until the cutter head faces to behind the machine as shown in Fig. 2.2-5. The cutter bit replacement work by the worker can be done facing to the cutter head. In these operation and works, the manual working space is completely isolated from tunneling face. The key technology is the sealing system of the structure.

The necessity of the replacement of every cutter bit can be judged visually, and all cutter bits can be replaced multiple times whenever.

A slurry shield of diameter 9.45m equipped with this mechanism was applied to the tunneling of rain water drainage tunnel in Yokohama city, and the cutter bits replacement work was executed at 2.5km point of 4.4km excavation.

(3) Cutter bits drawing out mechanism

The cutter bits are not installed directly on the cutter head. They are installed on the movable devices and when the cutter bits are worn out, they can be drawn out to the inside space of the shield machine with the movements. After the worn out cutter bits are replaced on the movements to new ones, they are pushed to the prescribed

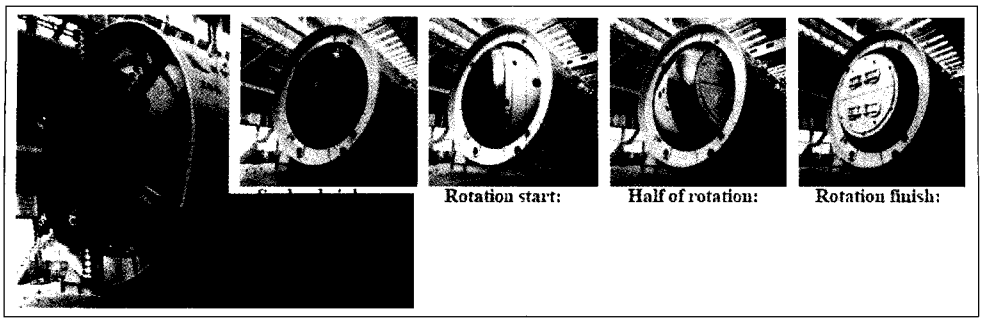

Fig. 2.2-5 Cutter drive rotation mechanism

position of the cutter head again. The following two mechanisms are developed and applied to the actual tunneling.

With these mechanisms, cutter bits replacement can be done multiple times whenever.

(a) Chain linked bit drawing out mechanism

Individual cutter bits fixed on each base block are connected like a row of chain link and installed on the guide rails installed on the spoke of cutter head. The chain linked base blocks can be slid on the guide rails. At the replacement work, a storage box is installed at the end of the guide rails and a hydraulic jack is connected to the chain linked base block through the storage box. After shutting and sealing the storage box, the gate installed in the cutter head is opened, and the base blocks are drawn into the storage box with cutter bits by the hydraulic jack. Then the gate is shut and box is opened for the replacement of worn out cutter bits (Fig. 2.2-6). After the replacement work in the box, the base blocks with cutter bits are pushed again onto the cutter spoke by the reverse process.

Comparatively the cutter bits in wide area are able to be replaced.

This mechanism was applied to EPB shield of diameter 5.8m for 1.2km length subway tunnel and EPB shield of diameter 7.16m shown in Fig.2.2-7

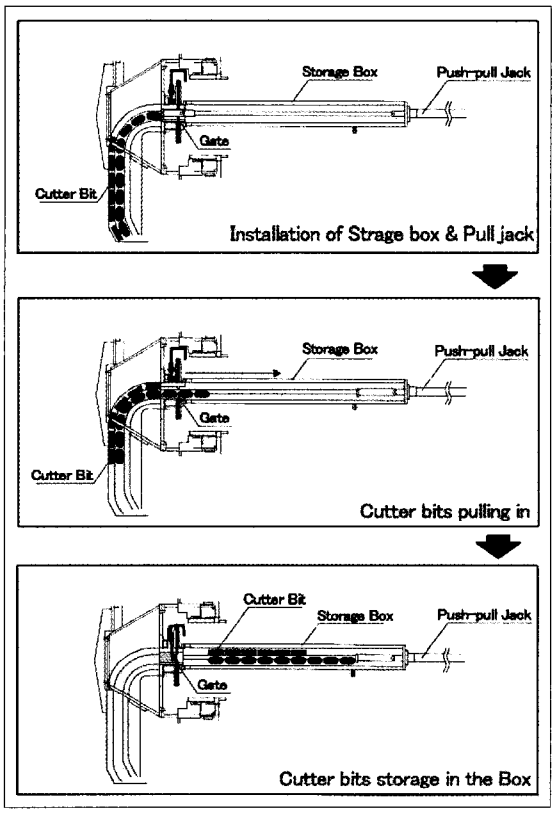

Fig. 2.2-6 Step for Cutter bits drawing

for 2.7km length sewerage tunnel in Kyoto city, they excavated the gravel layer and the exchange work was executed.

(b) Tube drawing out structure

The spoke of cutter head has triple tube structure. Cutter bits are installed in the innermost tube with

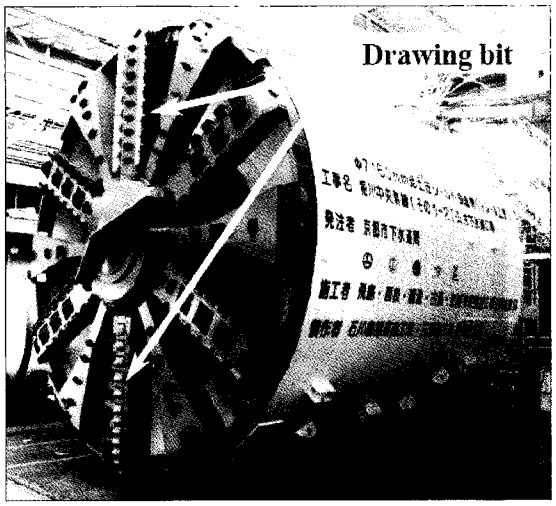

Fig. 2.2-7 φ7,160mm EPB shield machine Kyoto city sewerage project

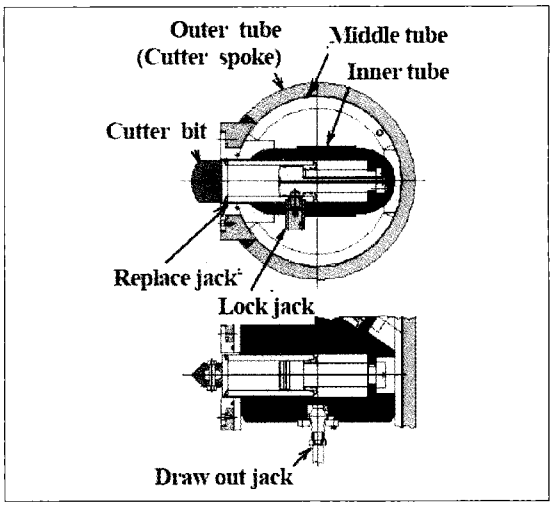

Fig. 2.2-8 Tube drawing system

hydraulic jacks and that tube can be drawn out by another hydraulic jack into the replacement work space located at the center of the cutter head. The middle tube can be rotate in the outermost tube. Initially, the cutter bits are Cutter bit stuck out to the tunneling face through the holes on middle and outermost tube. For the replacement, the cutter bits are retracted into the innermost tube and the middle tube is turned with the innermost tube to seal the cutter bit stick out hole on the outermost tube. After then, innermost tube is drawn out and the cutter bits in the tube are stuck out and replaced. After the replacement, new cutter bits are reinstalled at the prescribed position by the reverse process. Because of the structural complexity, the range of Draw out jack

replaceable cutter bits is comparatively small, at present. This mechanism was equipped on the EPB shields of diameter 5.2m for sewerage tunnel in Nagoya city and Sendai city. In each tunneling, the replacement work was already executed on the way of gravel layer excavation, diameter 5.2m for sewerage tunnel in Nagoya city and Sendai city. In each tunneling, the replacement work was already executed on the way of gravel layer excavation,

(4) Worker's accessible structure

For enough size of shield machine, the cutter head can be designed to have the spokes of large inner sectional area for cutter bits replacement work. The cutter bits replacement can be executed by the worker who invades into the large space of cutter spoke at where the cutter bits are installed with some special installation equipment with sealing system. The installation structure of the cutter bits is small and simple, and the replacement can be done multiple times whenever. The working space area in a spoke should be over about 0.8m square as shown in Fig. 2.2-9.

This structure was firstly equipped on the slurry shield of diameter 9.9m for double-track subway tunnel in Tokyo for the purpose of counter measure to cope with the remained old piles. And two times replacement and one time checking of the cutter bits wearing were executed. Also this structure was adapted to the EPB shield machine

for multi-purpose duct in Nagoya City (diameter 4.8m and tunnel length 6.8km). In each machine, some protective auxiliary cutter bits were replaced.

2.3 DEVELOPMENT OF HIGH DURABILITY CUTTER BEARING SEAL

For a lot of shield machines, polyurethane rubbers and/or nitrile rubbers are used for the material of the bearing seal, and most of the seals have single lip or multiple lips. Mitsubishi has already developed and adopted sealing system using multiple rows of polyurethane rubber made four lips seals, with the automatic grease filling system that fills grease to every room between the seal rows for aiming at the lubrication of the seal lips and the reversing prevention of the lips, as shown in Fig.2.3-1.

The durability of this sealing system is verified by the result of practical examination in the laboratory and many of the results of system checking after the completion of actual excavations.

In the examination, the slurry (including sand particles) pressure was loaded to the seals of 3m in diameter, and the decrease of the lip height and the increase of the depth of scratched scar on the metal plate surface on which seal lips slid were measured at some times in the rotation operation for 1,000 hours.

$$\delta_H = 0.489 \times L^{0.115}$$

The increasing of the scar depth on the surface of lip sliding plate δ_P(mm) is also confirmed as the function of the lip slide length L(m) and the sealing pressure P(MPa) shown as the following equation.

$$\delta_P = 4.77 \times 10^{-4} \times (L \times P)$$

The sliding length of seal lip L is decided by excavation

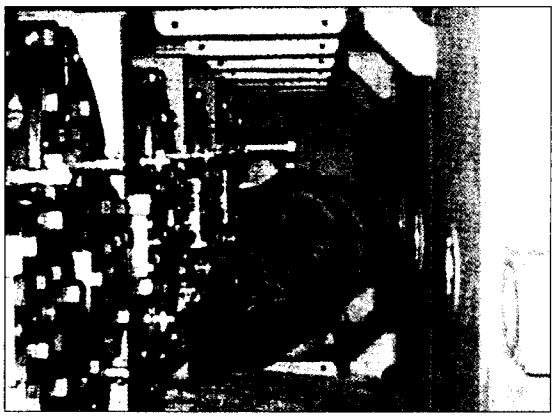

Fig. 2.2-9 Replacement work in spoke

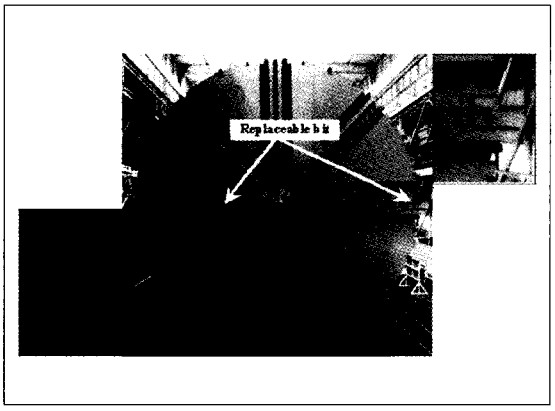

Fig. 2.2-10 Cutter head of Tokyo subway shield (9.9m dia.)

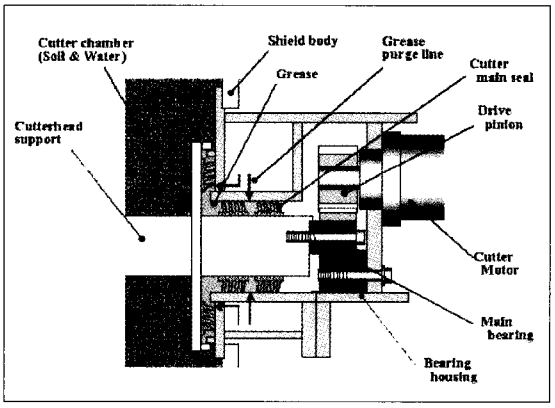

Fig. 2.3-1 Cutter Bearing Seal

length and the working condition of shield machine. So, assuming the working condition of the machine, the tunnel length which is able to excavate by one shield without any reparation of the equipped sealing system can be estimated with the allowable value of the lip height decrease and the depth of plate surface scar. Tab. 2.3-1 shows a result of a case study of estimation for capable length of tunneling by one machine, and it is recognized that the sealing system can be effective for more than 10km length tunneling under 0.3 MPa of underground water pressure.

3. DEVELOPMENT FOR HIGH SPEED ADVANCE TECHNOLOGY

For the tunneling in stable ground, the power up of cutter driving (torque and rotation speed) for dynamic excavation is effective for high speed tunneling. But for the tunneling in the soft subsoil, to put the displacement of the ground in the minimum, a low-speed and static proceeding of excavation should be required. In such case, it is necessary to shorten the cycle time of tunneling work to increase the advance rate. For this purpose, the time saving for segment assembly was paid attention.

For one of the ways for shortening the segment assembly time, various quick joint methods of segment are innovated. Refer separately because there are various reports for these innovations.

Tab. 2.3-1 Durability of Bearing Seal

Seal lip sliding velocity	: 15 m/min
Tunneling advance rate	: 1 m/Hr
Face pressure	: 0.3 MPa
Lip height decrease limit	: 1.5 mm
Plate wearing depth limit	: 1.5 mm
Capable tunnel excavation length capability (from view of lip height) (from view of plate wear)	 : 18.9 km : 11.6 km

Also, a mechanical improvement of increasing the operation speed of the segment erecting device and/or the thrust jack retracting speed is performed.

This section introduces the development of the mechanical technologies which make it possible to excavate simultaneously with the segment assembling work. In the assembly of the segment, the direction change of pitching and yawing moment for the shield machine is generated by the replacement of the promotion thrust jacks. For the accurate proceeding direction control of the shield machine along the planed line, this direction change of moment should be canceled.

3.1 DOUBLE STROKE THRUST JACK MECHANISM

The length of shield tail is designed in a length in which the segments of two rings can be assembled. And the stroke of thrust jacks is designed in the enough length to which the two ring segments can be pushed out. With such design, the simultaneous work of excavation with the segment assembly becomes possible according to the following procedures (shown in Fig.3.1-1).

(a) One segment ring is assembled in the rear area of the shield tail and in front of the ring there is a space for assembling the next segment ring.

(b) With starting the assembly of the next segment ring in the front space of shield tail, the excavation and the proceeding is started by pushing the rear segment ring with a thrust jacks.

(c) Along the progress of next ring assembly, some thrust jacks' pushing position is changed to the assembling ring from the rear ring.

(d) When the next ring assembly is completed while the excavation and proceeding of the length of one segment ring width, the state is return to (a) and the

work of (b) and (c) can be done continuously

The shield machine structure of this type was applied to two shield machines for French side tunneling of the Dover channel railway tunnel project for the first time (shown in Fig.3.1-2). On such machines, almost 1.5 times of number of thrust jacks comparing with the normal machine were installed as a countermeasure of canceling the pitching and yawing moment. The canceling method was that the thrust jacks installed at the opposite side of assembling position of one segment piece should be released. The installation of number of thrust jacks makes it easy to select the releasing jacks.

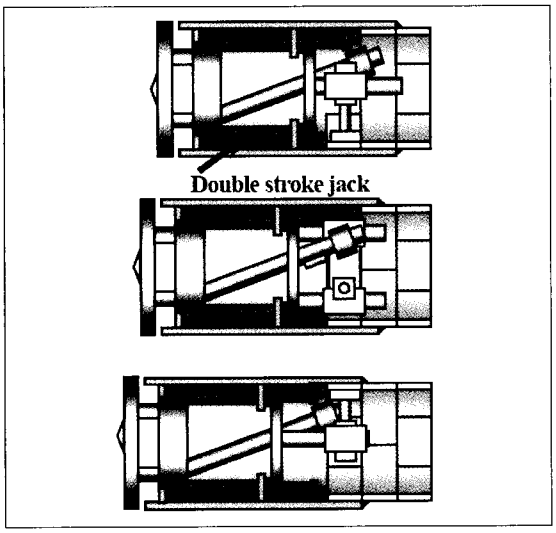

Fig. 3.1-1 Double Stroke Jack

Afterwards, there was a brush up study of this system, and the method that the number of jacks were grouped in some groups and the operating pressure of each group was controlled to cancel the generated moment was adopted to the slurry shield for the water conduit of Lake Kasumigaura in Japan.

In the Dover channel project, the EPB shield machine of diameter 5.59m had achieved maximum advance of 880m/month and the EPB shield machine of diameter 8.62m achieved maximum advance of 750m/month (both tunneling was done by three work shifts). The slurry shield machine of diameter 5.8m applied to Kasumigaura water conduit achieved maximum advance of 490m/month (two work shifts).

Because the total length of this type shield machine becomes long, the adoption to the tunnel which includes small curve radius is difficult. Moreover, it is naturally and necessary to control the segment erector to stay itself at the

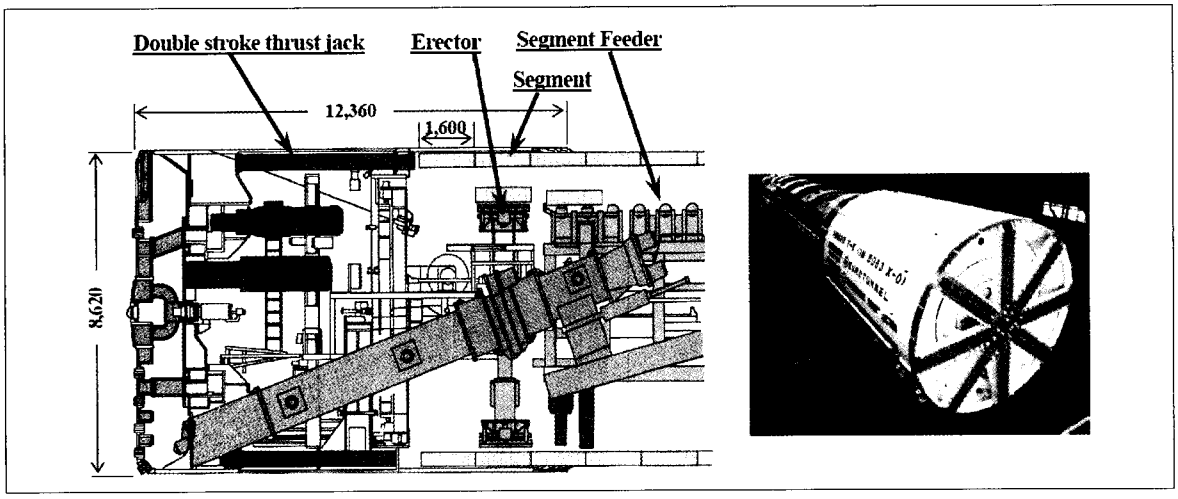

Fig. 3.1-2 Dover Channel Shield

ring assembling position while the shield machine advances.

3.2 INCH WORM MECHANISM

The shield shell is divided into front shield and rear shield. They are connected by thrust jacks and they are assembled with the sliding system of double cylinder structure. The rear shield is installed the auxiliary thrust jacks for the segment assembly. The machine style is just same as the double shield rock TBM.

The simultaneous advance of the machine with the segment erection is done according to the following procedures (shown in Fig. 3.2-1).

(a) The segment assembly is begun using the auxiliary thrust jacks in the tail of rear shield.

(b) The excavation and proceeding can be started at any time pushing rear shield by the thrust jacks.

(c) When the proceeding of the length of one segment ring width and the ring erection is completed, rear shield is pushed forward by the operation of the auxiliary thrust cylinder with the retraction of thrust jacks. And then the state is returned to (a).

The generated pitching and the yawing moment affect to the posture of rear shield but the displacement of rear shield is small comparing with the double stroke thrust jack system. The direction control of proceeding is achieved by the operation of thrust jacks. Moreover, the tail length and the segment erector are similar to a normal shield machine.

In this style machine, the sealing system is required in the slide structure between front and rear shield but the durability of the system is problem under high ground water pressure condition.

There are examples of adoption for a sewerage tunnel

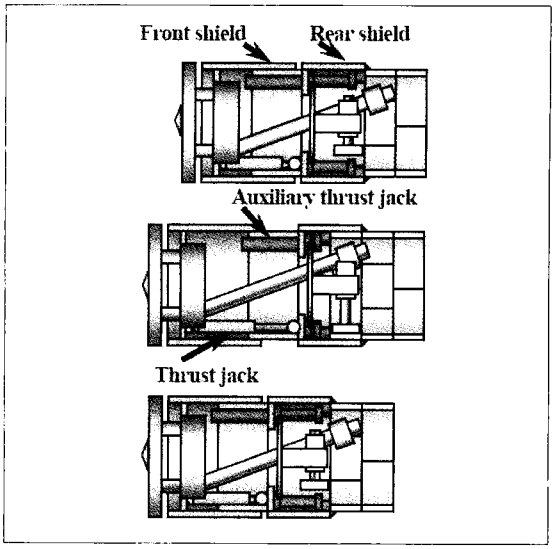

Fig. 3.2-1 Inch Worm

(diameter 4.7m: EPB shield) and a gas pipe line tunnel (diameter 2.9m: slurry Shield) in Osaka City, and the result is reported that the cycle time has been shortened by 30%.

4. CONCLUSION

In these years in Japan, the number of long tunnel excavation by one closed type shield machine is increasing rapidly. In some cases, the result of the mechanical development of cutter bit and high speed advance technology. It seems that the contribution level to the total construction cost saving by these technologies will be high though the machine cost increases a little compared with a normal shield machine.

The need for high speed advance is standing together with a long distance tunneling. It is necessary to consider about not only the shield machine but also other equipments and works for high speed tunneling. The reduction of cycle time for segment and the muck transportation considering the transportation system, the

shortening the extension working time for equipments in the tunnel and the cycle of muck disposal from the site, etc. should be considered totally at the planning stage. There are some examples of long and high speed tunneling projects with an automation of the segment handling and/or high-speed operation of rolling stocks, etc.

The cost saving seems to be achieved by ideas of planning engineers, and the engineers of Mitsubishi will support them by the knowledge and the experiences and will take best effort for development of new mechanical technologies for cost saving.

References

1. The Japanese Terra-mechanics Society: Talks about Wearing by Soil, Terra-mechanics Library, 2000.
2. Muro, T.: Experimental Study on the Impact Resistance of a Cutter Bit of a Shield Tunneling Machine, Japanese Society of Civil Engineering Reports, 1995.
3. Koyama, S.: Challenge to New Record of Shield Tunneling, Tunnels & Underground Vol.31 No.4, 2000.
4. Kosaka, A.: Replacement of Cutter Bit of Double Truck Subway Shield in Atmospheric Condition, Tunnels & Underground Vol.33 No.2, 2002.
5. Kaneko, K.: Development of Cutter Bit Replaceable Shield with Spherical Shell, Construction Machinery and Equipment, Vol.33 No.2, 1997.
6. Inoue, T.: Tunneling Machine for the Franco-England Dover Tunnel Project, Journal of the Japan Society of Mechanical Engineering, Vol.106 No.1015, 2003.

회장선출 등록 공고

학회 정관 제4장 12조(임원의 선출) 및 학회운영규칙 제4장 19조(회장선출)에 의거 차기 회장 선출을 위한 입후보자 등록을 다음과 같이 공고합니다.

》 등록기간 2008년 11월 1일(토) ~ 12월 1일(월)까지(1개월)

》 등록서류

- 후보 등록서 (학회서식) 1부
- 이력서 1부
- 정회원 50인 이상의 추천서 (학회서식) 1부

》 등록 장소 및 문의 학회 사무국(방문 또는 우편접수)

》 회장 선거 일정

2008. 12. 1(월)	후보자 등록 마감(18:00까지)
2008. 12. 19(금)	3인이내 후보자 결정(이사회) (입후보자가 4인 이상일 때)
2009. 1. 15(목)	투표용지 발송(2인 이상 후보자 등록시)
2009. 2. 20(금)	투표용지 접수마감(18:00도착분에 한함)
2009. 2. 26(목)	개표일

》 선거인단의 자격

2007년 2월 28일 이전에 입회한 정회원으로 2008년 12월 31일까지 모든 회비를 납부한 회원

》 기타

- 후보자 등록서 및 추천서는 학회 홈페이지 학회알림에서 다운로드하여 사용
- 추천회원은 회비 미납사실이 없는 회원만 유효

2008. 9

(사)한 국 지 반 공 학 회
회 장 이 송