Should you require further details on these articles or other information on tunnelling activities in Japan, please contact:

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Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2002

JAPAN TUNNELLING ASSOCIATION

CONTENTS

PREFACE

Hiroshi HAGIWARA

President
Japan Tunnelling Association

It is my great pleasure to have this opportunity to greet tunnel engineers throughout the world on this occasion of the publication of the 2002 edition of this biennial booklet of the Japan Tunnelling Association (JTA).

Due to the mountainous topography of Japan, its railways, from their early beginnings, have penetrated through mountain regions by tunnels to form the railway network. Highways too, especially expressways, have followed that example and constructed tunnels one after another.

On the other hand, having a small inhabitable land area, and especially due to the concentration of population into large urban areas, urban facilities such as subways, water supply and sewer systems have depended largely on underground utilization.

Further, having a complex geological structure, which also includes much spring water, Japan has been compelled to develop diverse methods of construction while advancing its construction projects.

JTA supports this technical development and has provided diverse technical information through its participation in the International Tunnelling Association.

From among numerous recent construction projects and items of information on technical development, representative examples have been selected for presentation in this 2002 edition of *Tunnelling Activities in Japan*.

I will be pleased if these articles will be useful to the tunnel engineers of the world.

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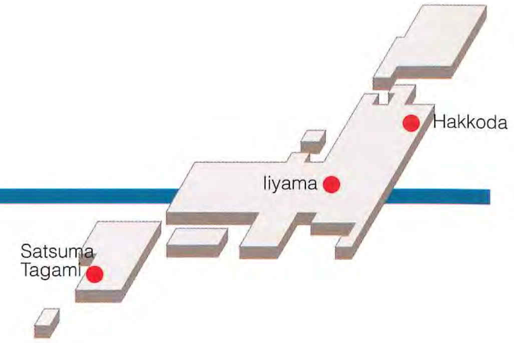
Construction Progresses on New Shinkansen Railway Lines



Kazutoshi YUYAMA
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The Japan Railway Construction Public Corporation is currently performing construction of a total of approximately 611km of the Tohoku, Hokuriku and Kyushu Shinkansen railway lines. This article presents an outline description of the main tunnel construction on each of these lines.

Tohoku Shinkansen Hakkoda Tunnel (World's Longest On-land Tunnel)

In the 81.2km long section of the Tohoku Shinkansen between Hachinohe and Shin-Aomori a total of 18 tunnels are planned, having a total length (49.9km) that is approximately 3/5 of the total length of line. Up to the present time, construction has been commenced on five of these tunnels, including Hakkoda Tunnel.

The 26.5km long Hakkoda Tunnel, which will be the world's longest on-land tunnel in rock, is being constructed by dividing it into six contract sections. As of December 2001, approximately 5.5km of excavation had been completed. The profile alignment has 1.0% rising gradients from both portals that meet in a summit very near the tunnel midpoint.

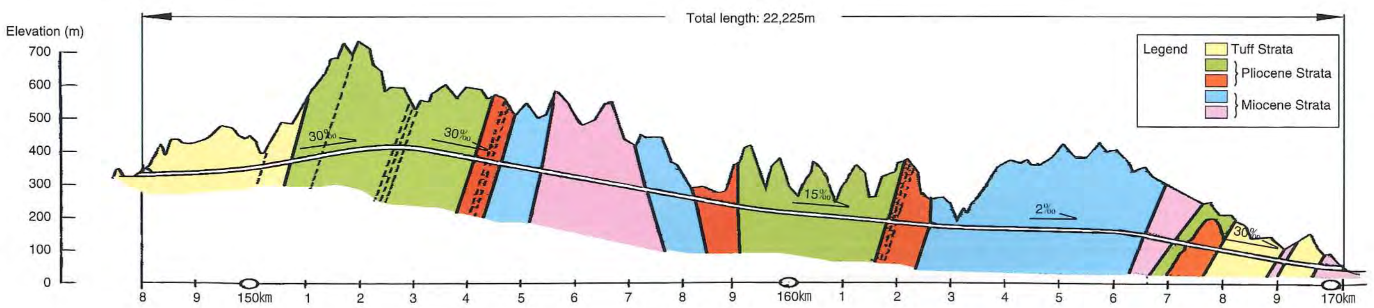
Except for a part at the western end, the rock that appears in the vicinity of Hakkoda Tunnel is Neocene bedrock. These Neocene strata principally consist of material of volcanic origin that is well consolidated as a whole, but this has undergone mineralization in part and mineral deposits are found scattered in the vicinity of intrusions. The geologic structure as a whole is a large folded structure having an anticlinal axis in the vicinity of the center of the tunnel so that the oldest strata are located at the center of the tunnel and gradually newer strata are located on each side of the anticlinal axis.

Hokuriku Shinkansen Iiyama Tunnel (Large Deformation Due to Squeezing Ground)

The Hokuriku Shinkansen is a line that extends from Tokyo through Nagano to Osaka, a distance of approximately 590km. Train service from Tokyo to Nagano was commenced in October 1997. Iiyama Tunnel, approximately 22.2km in length, is the world's fourth longest tunnel in hard rock. As of December 2001, excavation had been completed on approximately 6.7km of the tunnel, corresponding to 3/10 of its total length.

Because the geologic conditions at Iiyama Tunnel are similar to those at a tunnel where construction was very difficult due to squeezing ground pressure, excavation is being performed by full-face excavation with a short bench so as to keep loosening of the ground to a minimum. Also, the excavation cross section is large because of taking sufficient allowance for primary support deformation and considering space for placing secondary support. Because it is thought that a large load will not act on the secondary support, only a small allowance has been taken for deformation, and the

Profile of Iiyama Tunnel



support is designed as a thin ring shell consisting only of steel supports and shotcrete. The invert also is being performed by dividing it into primary and secondary stages with early cross section closure.

Further, sections of poor ground are being grasped ahead of time by advanced boring and elastic wave exploration. At the same time, inflammable gas and crude oil are being confirmed in advance and appropriate measures taken.

In the contract section where excavation is most advanced, success is being achieved against large deformation by performing geological investigations and applying the method of multiple support. Also, further economy is being sought by saving the provision of secondary support where the primary support does not reach the point of yielding.

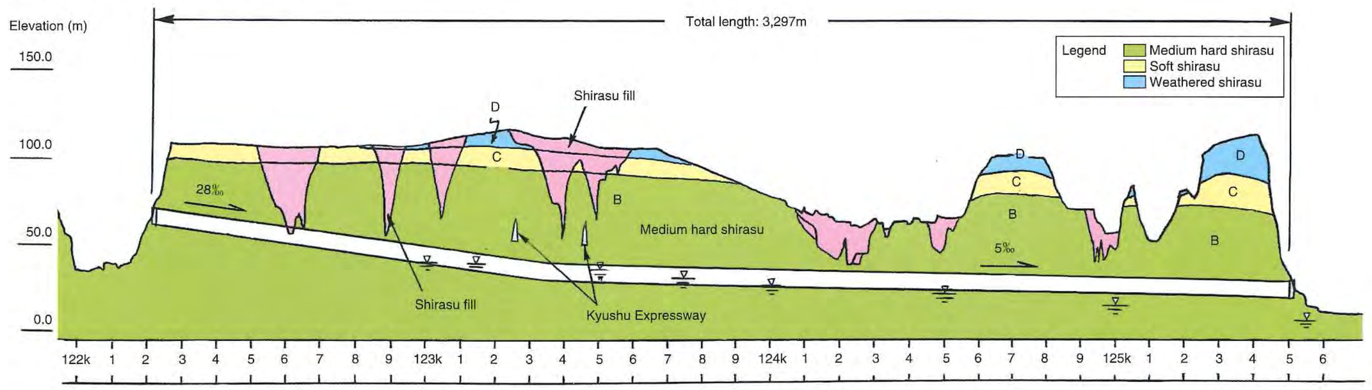
Kyushu Shinkansen Satsuma Tagami Tunnel (Auxiliary Methods for Tunnel Excavation through Shirasu Fill)

On the Kagoshima Route of the Kyushu Shinkansen, which connects the cities of Fukuoka and Kagoshima, construction of the approximately 128km long section from Yatsushiro in Kumamoto Prefecture to Kagoshima was commenced ahead of other sections. Now, almost all of the tunnel excavation in this section has been completed and track bed construction is in its peak period aiming for completion of this section at the end of 2003.

Satsuma Tagami Tunnel, 3.3km in total length, is located near the end of the railway line in Kagoshima. Residential tracts that were prepared by cutting and filling shirasu are located above the tunnel route, and the tunnel passes through several locations where old valleys were filled with shirasu. Shirasu is a weakly welded pumice material that shows a relatively large resistance to external force in a dry, natural condition, but when disturbed, as in fill material, it becomes granular like sand, looses the ability to consolidate and that which is located below the groundwater level can very easily become fluid.

Especially in sections where the bottom of the old valley extends into the upper half of the tunnel and the groundwater level is located above the tunnel, it was thought that the houses located directly above the tunnel might be damaged or otherwise affected if a cavity were to develop due to collapse of the face or washout of shirasu by the flow of groundwater accompanying tunnel excavation. To prevent this, presupport by a pipe roof and water cutoff by chemical grout injection were used as auxiliary construction methods. At the present time, excavation has been completed on approximately 3.2km of the tunnel, almost all of its total length, and work on the last, and longest, section of shirasu fill, approximately 200m in length, is being performed with great care.

Profile of Satsuma Tagami Tunnel



Shield Machine Enlargement and Underground Docking

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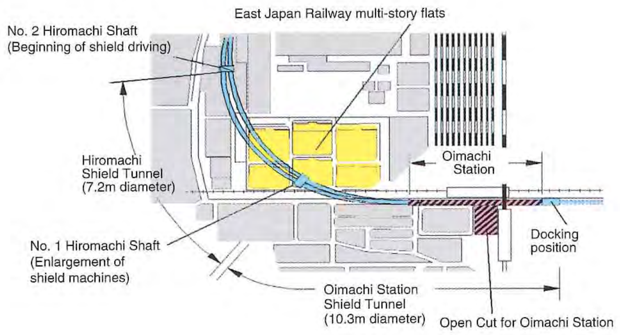
The Tokyo Waterfront Area Rapid Transit Line is a new railway line, approximately 12km in length, to connect the waterfront area in the southeastern part of the capital city of Tokyo. An 8km long section of the line is already in operation and further construction on this line is being advanced at the present time by the Japan Railway Construction Public Corporation under the severe conditions of a narrow site beneath congested streets.

The Hiromachi shield driven tunnels on this line between No.1 Hiromachi Shaft and No.2 Hiromachi Shaft are 230m in length and have a single track cross section of 7.2m shield machine diameter. On the other hand, the adjoining Oimachi Station shield driven tunnels required shield machines of 10.3m diameter to accommodate the station platforms within the tunnels. The shield machines of 7.2m diameter that were driven to No.1 Hiromachi Shaft were enlarged within the shaft to the 10.3m diameter for excavation of the following station cross sections. By making maximum use of the shield machines and their associated equipment in this way, substantial cost reduction was achieved.

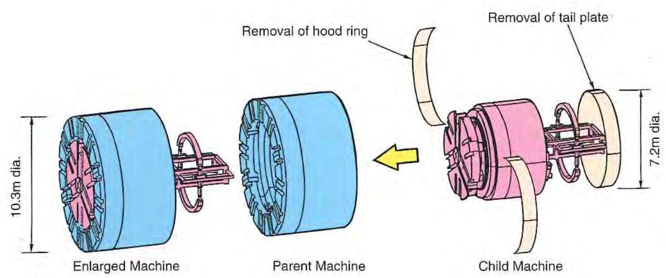
Enlargement of the shield machines was performed by inserting the small diameter "child" machine into the large diameter "parent" machine, an operation that can be performed in a short time and within a shaft of small area. The sequence of operations was as follows. (1) The parent machine that forms the outer ring of the large diameter shield machine was erected within the shaft. (2) The child machine that had completed excavation was pulled into the shaft. (3) The unneeded parts of the child machine such as the hood ring and the tail plate were cut and removed. (4) Using guide rails, the child machine was inserted into the parent machine. The main bodies of the parent and child machines were joined by welding their bulkheads and inserting cotters into the girders. The cutter faces were joined by extending the six extendable spokes on the child machine's cutter face. (5) The enlargement operation was completed by connecting the slurry supply and return pipes and adjusting the erector and the shape retainer.

Further, because an arrival shaft could not be constructed for the Oimachi Station shield driven tunnels due to the narrow width of the street above the tunnels, underground docking



with the 7.2m diameter shield machines that excavated from the opposite direction was performed by the penetration ring method, which does not require ground treatment. The sequence of operations was as follows. (1) The shield machine that came from the opposite direction arrived at the docking position first and waited. (2) The Oimachi Station shield machine excavated up to a position where the distance between its bits and those of the other machine was 50mm. The relative positions of the two machines were confirmed a small distance beforehand by horizontal boring between the two shield machines. (3) The two machines were joined by pushing out a penetration ring that was installed in the 7.2m diameter shield machine until it contacted a rubber seat ring installed on the bulkhead of the Oimachi Station shield machine. In this operation, a circular slit on the face of the Oimachi Station shield machine to receive the penetration ring was secured by retracting the six extendable spokes by which the parent and child machines were joined in the enlargement operation.

This technique for enlarging a small diameter shield machine into a large diameter shield machine and the technique of mechanical underground docking of shield machines that have different diameters, 10.3m and 7.2m, were both performed here for the first time. Through this shield machine enlargement and underground docking, substantial reduction of cost and shortening of the construction period were achieved.



Tunnel Construction by Pulling Small Steel Elements

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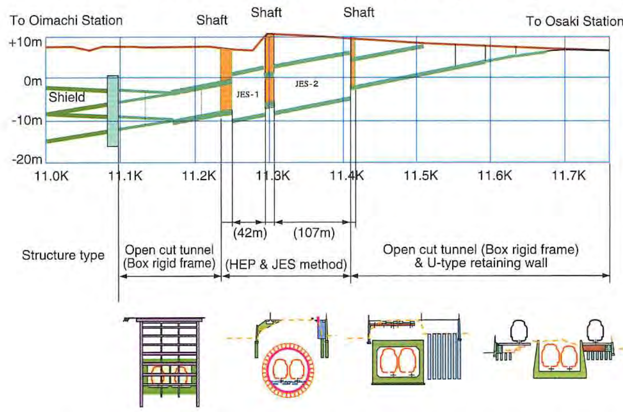
Deputy Manager, Tokaido-Sobu Division,
Tokyo Construction Office,
East Japan Railway Company

The Tokyo Waterfront Area Rapid Transit Line (popularly called "Rinkai Line"), a new railway line of approximately 12km length between Shin-Kiba and Osaki stations, is being constructed in two stages. The approximately 4.9km long section between Shin-Kiba and Tokyo Teleport stations was constructed first and was put into operation in March 1996. The approximately 7.4km long section between Tokyo Teleport and Osaki stations is now under construction, working toward start of train operation in December 2002.

In the approximately 680m long section of this line between Oi Shops and Osaki Station, the alignment crosses diagonally beneath tracks of the East Japan Railway Company and rises from a tunnel to the surface. The profile gradient is 3.3%, approximately 430m of the line is in tunnel and approximately 250m is in U-type retaining wall structure and level roadbed.

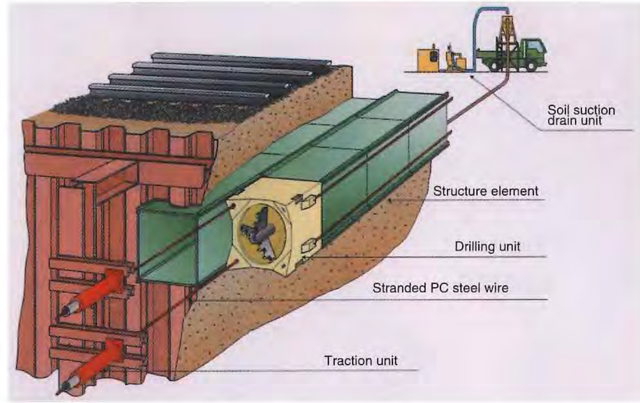
Tokyo Waterfront Area Rapid Transit Line (Oi Shops-Osaki)



Located in an area where the topography gradually falls off from the Megurodai highland to the lowland of the Meguro River, the geology consists of diluvial Tokyo beds, alluvial Yurakucho beds and fill. The structure is located in cohesive soil (Dc) of the Tokyo beds, Yurakucho beds (Ac, Ap) and fill (F), thus passing through extremely diverse soil beds.

For the approximately 180m long section of tunnel to be constructed directly beneath railway tracks at a depth of cover from 5.8m to 2.6m, a method of construction was sought which would satisfy the following conditions. (1) Double track operation of the Osaki Branch must be secured and any effect on the tracks must be small. (2) The method must be adaptable to diverse soil beds. (3) The shafts can be relatively small and must be adaptable to the restrictions of their location within the shops compound. (4) Construction time must be short. From among various non-cut-and-cover methods, the HEP (High-speed Element Pull) & JES (Jointed Element Structure) Method was adopted.

The HEP & JES Method is a method of constructing a tunnel structure by consecutively pulling through the ground and connecting into a circular configuration steel elements that are coupled together by a special type of joint, filling these elements with concrete to complete the tunnel structure, and finally excavating the interior of this structure to complete the tunnel.

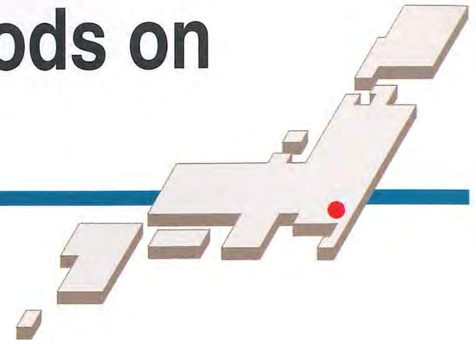


The steel elements have the shape of a trapezoid, 800mm in height with bases of 700mm and 800mm length, and were manufactured using 16mm thick steel plate (SM400). The elements were manufactured in 6m and 8m lengths, the maximum length that could pass through the shaft opening. These were successively welded together into elements of full tunnel length while being pulled through the ground.

This method is often adopted in the construction of grade separations with railways and highways, and there were examples of construction of crossings under double track railway lines (pulling distance on the order of 20m), but this was the first time for a pulling distance of 107m. Therefore, test construction was performed prior to the actual construction, and various definite improvements were made, including change of element configuration, improvement of the pulling equipment, and determination of the pulling force. In actual construction, pulling of the first element was begun in March 2001 and the pulling operations at the first and second tunnels were respectively completed in the middle of July and in October.

Through the completion of this construction within the prescribed time, it is considered that the superiority of this method, its safety and ease of performance, in the construction of grade separations with railways and highways has been proven, and that the method can be included in a broad comparison of construction methods.

Special Construction Methods on Hanzomon Subway Line



Kikuo NAGOYA Director, Technological Standards and Development,
New Line Construction Bureau,
Teito Rapid Transit Authority

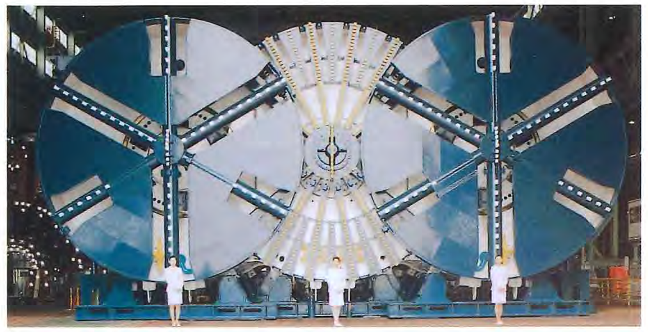
The 10.8km long section of the Hanzomon Subway Line between Shibuya and Suitengu-mae stations is in operation. This article introduces distinctive construction work being performed in the 6.1km extension of this line from Suitengu-mae Station to Oshiage Station.

At a location near Suitengu-mae Station where foundation piles of an office building having 10 stories above ground and one story below formed an obstruction to the passage of the circular cross section double track shield driven tunnel, the 49,000kN building load acting on seven foundation piles was transferred to an underpinning structure of inverted U-shape constructed of reinforced concrete beams and diaphragm walls, and the obstructing foundation piles were removed by the method of excavation for caisson type piles.

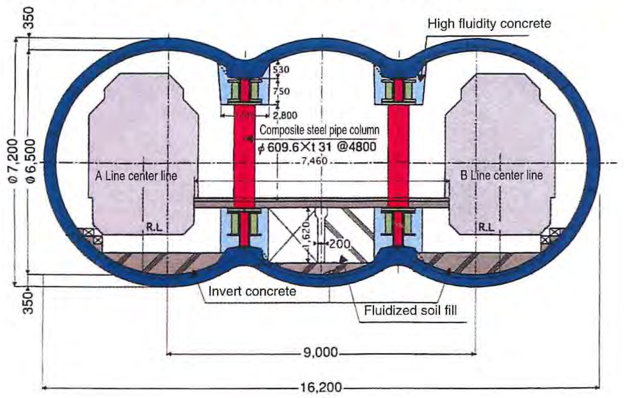
In a section of line where cross sections for a station and a storage track were to be constructed end-to-end for the long total distance of 618m, a triple face slurry shield machine was adopted in consideration of the effect of construction on the surrounding area. After driving the station section, the 14,000kN shield machine was moved through the intermediate shaft between the station and storage track sections using unit type rollers. The triple face shield machine has a configuration in which the two side cutter faces are in front and the center face performs oscillating motion, the first machine of this arrangement in the world. The two side cutter faces rotate and the center cutter face, which oscillates, is provided with a rotating core cutter at its center. Also, a reinforced concrete segmental lining was employed here for the first time in a triple face shield driven tunnel. Each lining ring is composed of 14 segments and two steel columns. In the station section, one out of four steel columns is a permanent composite steel pipe column. After the completion of excavation, longitudinal girders of composite structure, in which two steel channels are fixed to the columns, are constructed at both the top and bottom of the columns, and the three temporary columns in between are cut and removed for the station platform.

Construction of a pump room shaft that is located at the lowest point in the profile alignment involved excavation to a depth of nearly 50m. Due to various restrictions, including soft ground, confined groundwater under high pressure in the vicinity of the foundation bedding level and the limited area of the construction site, the shaft was excavated by underwater excavation while a ring lining of steel segments was erected and pressed into the ground by jacking against a reaction obtained by ground anchors.

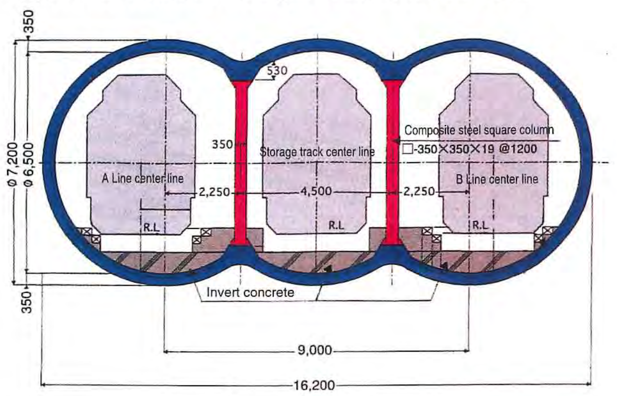
In a section where soft alluvial cohesive soil continues, a high density slurry shield machine of 9.6m diameter was adopted, a type that has compact muck treatment equipment. Economy was achieved in this machine by adopting a cutter frame of a new type by which an excavation cross section similar to that of the shield machine is obtained by attaching the cutter frame eccentrically to several drive shafts that produce parallel link motion as they are rotated.



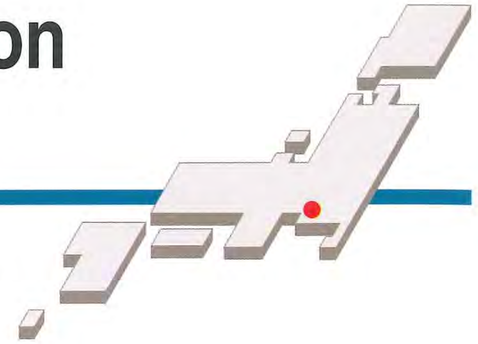
Triple Face Shield - Station Cross Section



Triple Face Shield - Storage Track Cross Section



Multi-Circular Face Shield on Nagoya Subway Line No.4



Tadashi KAWAMURA Director, Construction Office 3,
Construction Department, Transportation Bureau,
City of Nagoya

The shield tunneling method (open face shield with manual excavation in compressed air) was adopted for the first time in Japan in 1960 in the construction of the tunnels between Ikeshita and Kakuozan stations on Nagoya Subway Line No.1. Since then, remarkable technical advances have been made and closed type mechanical shield machines of various types have been developed such as earth pressure balanced (EPB) machines, slurry type machines and others.

Now, in the construction of the tunnels between Sunadabashi and Aratamabashi stations on Nagoya Subway Line No.4, which is now in progress, double circular face shield machines have been adopted in seven construction sections, the fifth example in the whole country, and driving has commenced. By connecting to Sunadabashi and Aratamabashi stations, which are already in service, this line will join to form a loop line, and construction is being advanced toward the goal of full loop operation starting in FY2004.

This article will describe one of the seven construction sections, Motoyamakita Construction Section between Chikusadai (tentative name) and Motoyama stations.

Outline of Motoyamakita Construction Section

In this construction section, a 1238.4m long tunnel of double circular face cross section is to be driven by the Rheological Foam Shield Tunneling Method, a type of EPB shield, from a launching base at Chikusadai Station to Motoyama Station. The horizontal alignment is straight for a long distance and has a curve of 300m radius at the arrival end of the drive. The profile alignment includes a 2.7% descending grade for the long distance of 740m. The minimum depth of cover is 9.4m and the maximum is 32.3m. This section is located in the eastern hilly area of the city where the elevation is on the order of 50m above sea level. The soil consists of alternating strata of sand and silty clay of the Pliocene Yadagawa Formation.

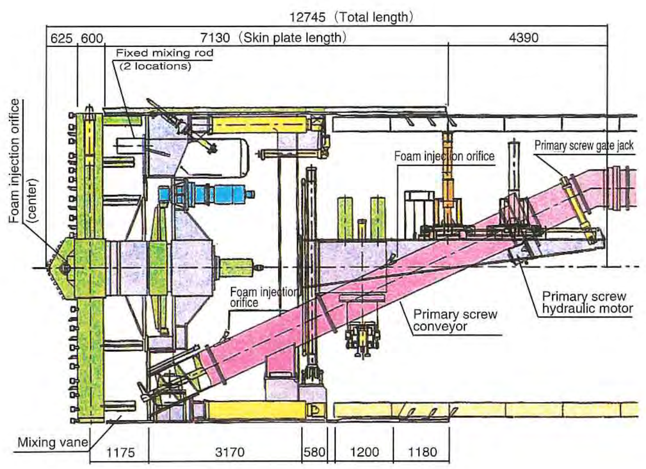
The shield machine has outside dimensions of 6520mm diameter and 11,120mm total width, and is equipped with 32 thrust jacks that can generate a total thrust of 68,632kN (7000t). The excavation cross section has an area of 60.7m². The reinforced concrete and ductile segments (the latter for use in the connection with an underground substation and at locations having superimposed building loads) have outside dimensions of 6300mm diameter and 10,900mm total width, 300mm thickness and 1200mm ring width. Each ring is composed of 11 segments including the center column.

Continuous Belt Conveyor

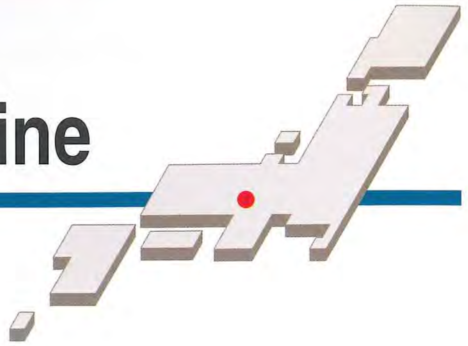
While remarkable advances have been made in the mechanization of shield machines in recent years, the transport of excavated soil material from EPB shield machines is still performed chiefly by battery locomotive drawn muck cars. At Motoyamakita Construction Section, muck transport was studied from the view of improvement in safety and operating environment, effect on the surrounding area, and capacity and efficiency of transport. From this study, it was decided to employ a continuous belt conveyor system with a belt width of 610mm.

Outline of Conveyor System

The soil material, which has been mixed with rheological foam within the pressure chamber of the shield machine, is discharged from the screw conveyor, automatically measured for weight and volume by a scale conveyor mounted on the support train, and then transported to outside the tunnel by the continuous belt conveyor together with a vertical belt conveyor. This is made possible by automatically pulling out the conveyor belt that is capable of extension as shield driving advances, and has the advantage that total driving time can be shortened because the waiting time that becomes a problem in the case of rail transport does not occur. Also, a storage cassette that is capable of storing a 300m length of extension belt is located at the launching base. The entire length of belt conveyor is driven by a single main drive motor and transports the soil material at a speed of 168 m/min. This system is operating in two lines, one for each of the two circular faces of the shield machine.



Box Shape Double Track Cross Section Shield Machine



Yoshihiro NAKAGAWA
Director, Construction Department,
Kyoto Municipal Transportation Bureau

In the city of Kyoto, a total of approximately 50km of high speed metro lines have been planned, consisting of the Karasuma Line that passes through the center of the city in the north-south direction and the Tozai Line that crosses the city center in the east-west direction. Out of this total plan, the 13.7km section of the Karasuma Line between Takeda and Kokusai Kaikan stations and the 12.7km section of the Tozai Line between Daigo and Nijo stations are now in operation, together carrying approximately 400,000 passengers per day. At the present time, the section of the Tozai Line between Daigo and Rokujizo stations is under construction aiming for start of train operation in 2004. On this extension, a shield machine having a large rectangular cross section was adopted for the first time in Japan.

Planning

On this project, the 760.79m long section of tunnel between Rokujizo Station and the adjacent Ishida Station, which consists of a 57m long crossover section and a 703m long running track section, is to be constructed using a high density slurry type shield machine of rectangular cross section from a launching shaft (21.21m long) at the north end of Rokujizo Station. The tunnel is planned to have outside dimensions of 6500mm in height and 9900mm in width. The crossover section (single tier, single span) is planned with a lining of sandwich type composite segments that have a 500mm girder depth and are fully covered by steel skin plate. The running track section (single tier, double span, with center pillar) is planned with a lining of ductile steel segments that have a 350mm girder depth. The shield machine will drive through diluvial sand and gravel at a depth of cover of 8.2m to 14.4m. A "Wagging Cutter Shield," which is equipped with cutter heads that perform an oscillating (wagging) movement, was adopted as the shield machine that would be capable of excavating this irregular cross section, and this machine is now being assembled at the site.

Preliminary Studies and Testing

Design of the two types of segments was performed by beam-spring model in which joints are considered as springs and the segments themselves as beams. Because of the unprecedented scale and configuration of these segments, full size loading tests were performed on both types to confirm the adequacy of their design prior to construction. The amounts of strain and deformation that were measured in these tests were somewhat less than the predicted amounts, thus confirming the safety of the lining structure and the adequacy of the design method. For the shield machine, erectors were developed that can be controlled on six axes to handle the two differing types of segments, and erection tests are being planned to confirm their performance. Also, confirmation of the performance of the overcutters that excavate the non-circular portions of the tunnel face has been obtained through durability tests performed under conditions that were close to those that will be actually encountered.

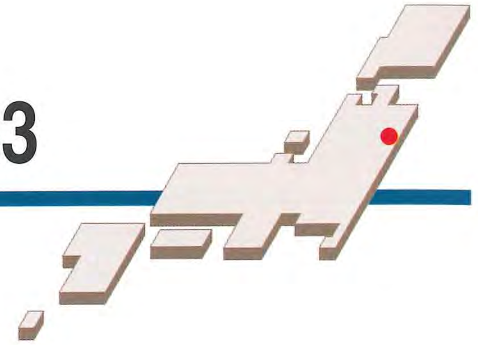
Future plans

Because the amount of deformation of the lining is large in the crossover section, the machine is to be equipped with shape retainers to counter loads during construction. Further, monitoring of various types is being planned to grasp the loads acting on the lining structure, its behavior under these loads, and the effect of construction on the surrounding ground. Construction was commenced in October 1999 and launching of the shield machine is scheduled for the spring of 2002.

Loading Test on Sandwich Type Composite Segment Rings

Loading Test on Ductile Steel Segment Rings

Sennin Tunnel on National Highway Route 283



Toshisada KOMURA
Director, Sanriku National Highway Office,
The Tohoku Regional Bureau,
Ministry of Land, Infrastructure and Transport

Outline of Sennin Pass Highway

National Highway Route 283, on which Sennin Tunnel is located, is a main highway that extends from the city of Kamaishi on the Pacific coast of Iwate Prefecture to the inland city of Hanamaki. As a means of inter-city communication and connection between the Sanriku Coast centered on Kamaishi and the Kitakami River Valley High Technology Industrial Area located inland, this highway, which is administered by Iwate Prefecture, is an important transportation route for the balanced development of the prefecture.

However, the 26.1km section of highway that includes the presently used Sennin Tunnel (2.5km long, 5.1m wide, completed in 1959) is a narrow and tortuous road with a steep gradient. Further, with freezing in the winter season, the maintenance of safe and smooth highway traffic is difficult.

Accordingly, Iwate Prefecture and the Ministry of Land, Infrastructure and Transport began work on Sennin Pass Highway as an improvement project in 1992 and this highway is to be incorporated into the Tohoku-Odan Expressway Kamaishi-Akita Route in the future. Sennin Pass Highway is a mountain highway that includes four tunnels that have a total length which is equivalent to approximately 50% of the 18.6km total length of the highway. The longest of these four tunnels are the 4485m long Sennin Tunnel and the 3000m long Goyozan Tunnel.

Special Features of New Sennin Tunnel Construction

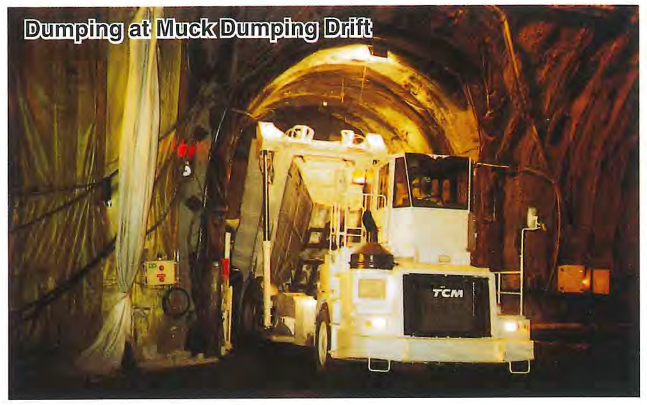
(1) Although this is a long tunnel, construction is being performed from the Kamaishi end only. Because the profile gradient is a uniform ascending gradient from the Kamaishi end, the main tunnel is being excavated using wheeled equipment and the pilot tunnel using rail mounted equipment.

(2) A glory hole is being employed in the mucking operation. At first the plan was to excavate the initial 100m length of the pilot tunnel to an enlarged cross section and locate a muck stockyard and temporary construction equipment in this space. Muck from the main tunnel was to be stockpiled in the portal yard in front of the operation platform and then the muck was to be taken from each of these locations by a second hauling operation. Because of this, severe vehicle congestion was foreseen in the narrow portal vicinity, including the primary and secondary muck hauling vehicles as well as other construction vehicles, leading to reduced operational efficiency and safety. Thus, rethinking of the plan became necessary. To separate the muck hauling operation from other operations, a muck dumping drift was excavated between the pilot tunnel and the main tunnel at a position 45m from the portal and a glory hole was excavated at the midpoint of this muck dumping drift to connect to a muck loading tunnel located 20m below. In this way, it became possible to perform the muck hauling operation without effect on other operations.

(3) Container dump trucks are being used in the muck hauling operation. Containers that have been loaded with muck following a round of blasting are temporarily set down near the face, thus shortening the muck handling cycle near the face. Also, because secondary muck hauling can not be performed during the nighttime due to the environmental condition that the route of secondary muck hauling to the muck fill area passes through a residential area, containers loaded with muck are temporarily set down within the tunnel and hauled during daylight hours on the following day.

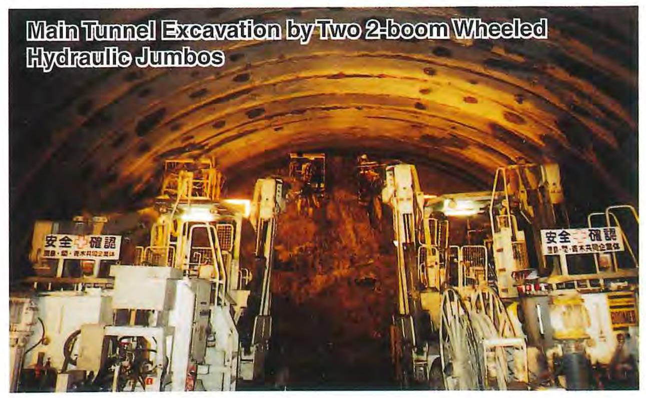
(4) Caverns of small scale were confirmed at the entrance end. Because the geology at both the entrance and exit ends consists of limestone and there are limestone caverns, such as those called Rokando and Byakurendo, at the exit end of the tunnel, the appearance of caverns peculiar to limestone was foreseen.

(5) The steep topography at the portal was overcome by constructing a temporary platform at the portal as an operations yard.



Dumping at Muck Dumping Drift

Portal Section of Pilot Tunnel



Main Tunnel Excavation by Two 2-boom Wheeled Hydraulic Jumbos

Large Cross Section Tunnels on New Tomei Meishin Expressway

Tatsuro IWASAKI
Senior Staff Engineer, Engineering Department,
Japan Highway Public Corporation

The New Tomei Meishin Expressway is a new expressway route of approximately 502km total length that is formed by the New Tomei Expressway, approximately 328km between Tokyo and Nagoya, and the New Meishin Expressway, approximately 174km between Nagoya and Kobe.

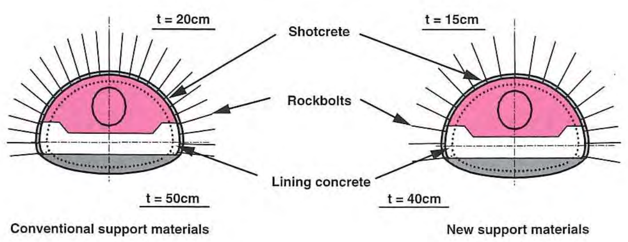
The route of the New Tomei Meishin Expressway as a whole passes through more mountainous areas than the present Tomei Meishin Expressway. Because of this, the total number of tunnels presently planned is 167, having a total length of 224km which equals approximately 25% of the total length of eastbound and westbound line. In comparison with the figure of 2.6% for the present Tomei Meishin Expressway, this ratio of tunnels is much larger. Also, the tunnels on the New Tomei Meishin Expressway are large-scale linear structures that have an excavation width of approximately 18m and an excavation cross section area of approximately 190m², a large cross section that is approximately 2.5 times that of a two-lane tunnel.


Route Map

Development of Rational Support Structures

In determining the support structures for the New Tomei Meishin Expressway, numerical analysis and other theoretical design studies were performed, and then the final structures were determined after performing verification through test construction using the support structures determined by numerical analysis.

Also, the use of support materials of conventional material specification would result in a quantity of support of unprecedented large scale, thus leading to various problems such as lose of ease of operation, decrease in rate of progress due to increase in cycle time, and how to secure quality. Therefore, the adoption of new support materials of high strength and high standard is being studied to solve these problems, and thus achieve improvement in economy and ease of operation.



Development of Efficient Excavation Methods

Considering various factors including past experience, the basic excavation methods to be used in the New Tomei Meishin Expressway tunnels are the method of upper heading and bench in locations where the ground is relatively good, and the method of upper heading and bench with a center pilot in the upper heading in locations where face stability is poor.

In addition to these excavation methods, the TBM Pilot and Enlargement Excavation Method is to be introduced as a new excavation method for the New Tomei Meishin Expressway tunnels. With the TBM Pilot and Enlargement Excavation Method, by performing a pilot excavation by TBM within the tunnel cross section in advance, various beneficial effects such as confirmation of geological conditions and drainage into the pilot are expected, so that safe and efficient enlargement excavation can be performed.

Construction Example 1: Shimizu No.3 Tunnel

Test construction at Shimizu No.3 Tunnel (Neocene sandstone and mudstone) was performed as a test of the TBM Pilot and Enlargement Excavation Method in rock that ranges in hardness from medium hard to soft and to confirm the applicability of new support materials. Regarding the TBM Pilot and Enlargement Excavation Method, the anticipated effects of the pilot heading were verified. Especially, efficient excavation was achieved due to improvement in face stability and the extension of the length of advance per excavation cycle that this made possible. In the upper heading at Shimizu No.3 Tunnel, a maximum monthly advance on the order of 110m was recorded. Regarding the applicability of new support materials, through test construction using high standard support materials such as new high strength shotcrete, new high strength fiber reinforced shotcrete, new high standard steel arch supports and new high strength lining concrete, the stability of a tunnel in which support materials of new specification were adopted was verified, the problems of improving ease of construction and securing quality in applying these support materials were surmounted and a thinner and lighter support structure became possible.


Shimizu No.3 Tunnel


West Portal of Westbound Shimizu No.3 Tunnel

Construction Example 2: Ritto Tunnel

At Ritto Tunnel (granite), test construction by the TBM Pilot and Enlargement Excavation Method is being performed in hard rock. One objective sought at Ritto Tunnel was high speed TBM operation by systemization of TBM excavation including prediction of conditions ahead of the face and the measures to be taken beforehand. Also, because the ground at Ritto Tunnel is hard rock with developed planes of discontinuity and the tunnels have a large, flattened cross section with a wide arch, there was apprehension concerning the danger of rock falling along these planes of discontinuity. For this reason, the technique of key block analysis was introduced to study the stability of the tunnel during construction and after opening to traffic with attention focused on the behavior of this ground that has developed discontinuities. Key block analysis is a technique by which tunnel stability at the time of enlargement excavation is estimated from discontinuity information obtained from the walls of the TBM pilot and is performed for the objective of achieving safe and rational enlargement excavation by performing advance reinforcement of the tunnel crown from within the pilot if the ground is judged to be unstable.


Enlargement Excavation at Ritto Tunnel

Construction Example 3: Suzuka Tunnel

At Suzuka Tunnel, excavation was performed by the TBM Pilot and Enlargement Excavation Method, but it was decided to seek an attainable, low cost method of high-speed construction so as to fully realize TBM effectiveness.

Borehole logging was adopted in which the conditions ahead of the face are predicted from drilling data and confirmation of the condition of slime from non-core boring performed by a large rock drill mounted on an operations deck located in a large space at the top of the TBM that was secured, together with spaces at the sides of the TBM, by lowering the main beam and changing the positions of the thrust jacks at the time of design and manufacture of the TBM. Because accurate information on geological conditions for a distance of approximately 50m ahead of the face can be obtained in a short time (about four hours) and at low cost through the use of this logging technique, it became possible to accurately grasp geological conditions, even including fractured zones, by incorporating this technique into the standard cycle of TBM operation and performing the investigation throughout the length of line. Also, by locating the operator's position near the face, it became possible for the operator to confirm each operation directly by eye. In this way, efficiency and safety were improved, as well as the operating environment.

By employing these systems for high-speed operation, a capability for rapid construction (430m average monthly advance and 885.7m maximum advance in one month) was fully exhibited in holing through the TBM pilot in the eastbound tunnel.


Boring for Advance Exploration at Suzuka Tunnel


TBM Pilot

Nishi-Shinjuku Shield Tunnel on Metropolitan Expressway Central Circular Route

Hisamitsu HANNO — Manager, First Design Division, First Construction Department, Tokyo Construction Bureau, Metropolitan Expressway Public Corporation

Kenji NAMIKAWA — Assistant Manager

Metropolitan Expressway System

The Metropolitan Expressway system forms a network of 270.4km of expressways in the Metropolitan area centered on Tokyo. Being utilized by an average of 1.16 million vehicles and about 2 million persons each day, the system performs an important role in support of the everyday life and economic activity of the Metropolitan area. Toward the objective of improving its service through further expansion of this network, including loop expressways, the early construction of which is the subject of strong public demand, the Metropolitan Expressway Public Corporation is engaged in the construction of the Central Circular Route, the loop expressway that is nearest to the center of Tokyo.

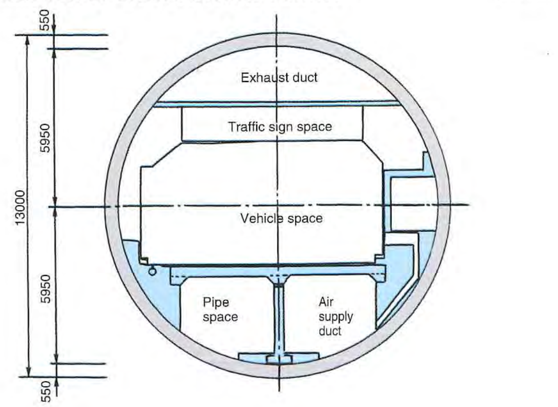
Central Circular Shinjuku Route

The Central Circular Route is a 46km long loop expressway that is planned to circle the urban center at a distance of approximately 8km. The approximately 20km long eastern section of this line is already open to traffic. The Central Circular Shinjuku Route (hereinafter called Shinjuku Route), which is presently under construction, forms the 11km long western section of the Central Circular Route. In the construction of Shinjuku Route, which is located along Tokyo Loop Road No.6 (also called Yamate-dori), tunnel structure was adopted for nearly its entire length, except for junctions, to preserve the good urban environment and achieve effective three-dimensional utilization of limited urban space. Further, in consideration of effect on the residential environment and traffic environment during the construction period, the shield driving method was adopted for approximately 7/10 of the total length of tunnel.

Nishi-Shinjuku Shield Tunnel

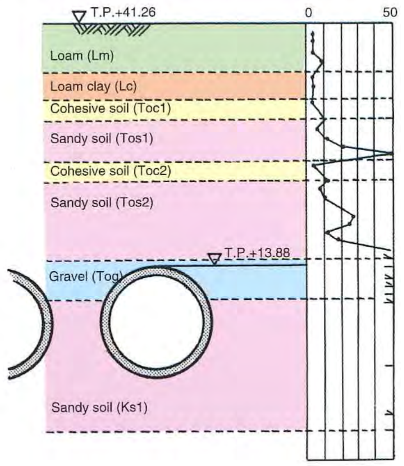
The Nishi-Shinjuku Shield Tunnel is a twin tunnel that is being constructed by driving beneath important structures such as the Keio Railway and the National Highway Route 20 underpass for a distance of approximately 600m from a launching shaft that was constructed in front of Tokyo Opera City, which is located at the west side of Shinjuku Urban Center, to a reversing shaft that was constructed at Hatsudai. Here the shield machine was reversed in direction by turning 180° and then it was launched again to return to the original shaft. These are the first shield driven tunnels of large excavation diameter to be commenced on the Shinjuku Route. As vehicular tunnels they are the first substantial project since Tokyo Wan Aqua-Line. This project to excavate tunnels of this size beneath important urban thoroughfares at a depth of cover that ranges from 21m to 27m was faced with extremely severe conditions.

Cross Section of Shield Driven Tunnel (unit: mm)



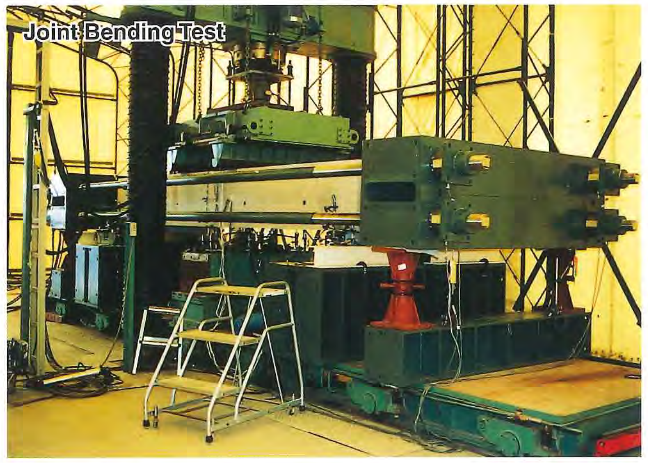
Geological Environment

The project site, located in the southeastern part of the Musashino Plateau, is on plateau land where Kanto loam remains on its surface to a depth of 5m to 10m. From the surface downward the soil layers consist of Tachikawa-Musashino loam, Shimosueyoshi loam, Tokyo beds (sand, clay), Tokyo gravel, and Kazusa beds (sandy soil, consolidated clay). The ground at the level of GL−25m to GL−32m, through which the tunnels pass, consists of Tokyo gravel (Tog) and Kazusa sand (Ks) that have N-values exceeding 50. Tokyo gravel chiefly consists of gravel in the size range of 10mm to 80mm but it also includes cobbles that have a maximum size on the order of 150mm. Also, with confined groundwater under an average pressure of 200kPa, the control of slurry density and viscosity, as well as measures to cope with gravel, are extremely important.



Design of Segmental Lining

Through a study of ease of operation, economy and past construction experience, the lining structure selected for these tunnels was a segmental lining composed of flat reinforced concrete segments with connections using ductile steel bolt boxes and short bolts. Considering the radius of curvature of the highway and the urban location of the project site, the segmental lining was divided into rings of 1200mm width, with each ring divided into 10 segments of equal length to be erected with the joints staggered between rings. This segmental lining was designed by the rational design method of "beam-spring model" analysis in which a "rotational spring constant" that considers axial force was used in the joints between segments in a ring, and a "shear spring constant" that considers friction was used in joints between segment rings. Also, design verification was performed by executing tests for the purpose of evaluating the rotational spring constant and the flexural capacity of the joints between segments in a ring.


Joint Bending Test

Slurry Type Shield Machine

Because any effect on the surrounding ground must be kept to a minimum, a slurry type shield machine was adopted for the Nishi-Shinjuku Shield Tunnel in consideration of the ground conditions, past experience in large cross section tunnel driving by this type of machine and other factors. Also, because the machine must drive through a sharp curve having a minimum radius of curvature of 204m due to the highway alignment, the machine was equipped with an articulation mechanism that is capable of a maximum deflection of 1.5°. The shield machine has an outside diameter of 13.23m, is 13.12m long and weighs approximately 28,000kN. As an articulated shield machine, this is the largest in the world, exceeding the machine of 12.34m outside diameter that was used in constructing the Shibukawa Storm-water Reservoir in the city of Kawasaki.

Ground Freezing

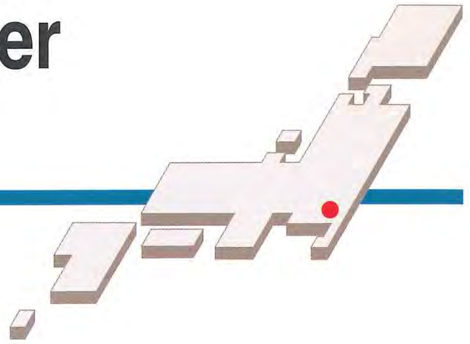
Because sand or gravel are predominant in the ground at the level where the shield machine leaves and enters the shafts and the groundwater pressure is high, ground freezing was adopted as the method of protecting these openings. In ground freezing, an operation period of approximately 70 days was necessary to form the required wall of protective frozen ground. Following completion of launching preparations, the freeze pipes and temperature monitoring pipes were removed and the shield machine was launched, the machine melting and excavating through the frozen ground. As further protection at the launching opening, chemical grout injection was performed by the Multi-phase Twin Pipe Strainer Method for a distance approximately equal to the length of the shield machine to prevent the flow of groundwater into the shaft.

Shield Machine Turning for Second Use

Because the Nishi-Shinjuku Shield Tunnel is relatively short in length, only 600m, economy is being achieved by using the shield machine twice. In order to turn the shield machine within the Hatsudai Shaft following its arrival after the first drive, the center wall was left out at the time of turning. This shaft is a rectangular structure that is 31m long, 38m wide and approximately 40m deep. After the shield machine was pulled into the shaft and onto the cradle, the shield machine and cradle were turned using jacks and 90mm diameter steel balls as ball bearings. Because a horizontal surface of high precision was required in the floor in order to make the steel balls roll smoothly, it was necessary to secure satisfactory horizontal precision by laying steel plates on the surface of the bottom slab.


Schema of Shield Machine Turning for Second Use

Immersed Tube Tunnel under Tokyo West Passage



Kazuo OCHIAI
Design Section Manager,
Tokyo Port Offshore Land Reclamation Office,
Bureau of Port and Harbor,
Tokyo Metropolitan Government

Seaside Road is a highway that extends from Jonanjima in Ota Ward to Wakasu in Koto Ward, a distance of approximately 8.0km. The approximately 3.4km long section of this road from Jonanjima to the Outer Central Breakwater Reclamation Area (including a bridge to connect to the Inner Central Breakwater Reclamation Area) is presently under construction, and the tunnel where this road crosses under Tokyo West Passage, called Tokyo West Passage Tunnel, is scheduled for completion at the end of FY2001.

Objective and Outline Description

Seaside Road is being constructed to provide a road that will connect reclaimed land areas on the seaward side of Expressway Bayshore Line for the purposes of smoothing the flow of port traffic, solving traffic congestion in Waterfront City and dispersing vehicles carrying waste material to the reclamation areas. The tunnel, which has four lanes with a design speed of 60 km/h, is 1969m long, including a 1329m long section of immersed tube tunnel.

Tunnel Characteristics

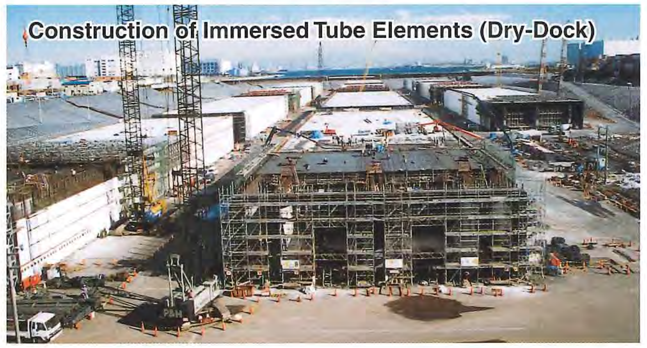
(1) This tunnel is one of the longest of the immersed tube type in Japan, exceeded only by the Tamagawa Tunnel on the Metropolitan Expressway. To accommodate the passage of large oceangoing vessels, the tunnel is located at a depth of −29m, making it the deepest immersed tube tunnel in the country.

(2) Tokyo West Passage is the main fairway into Tokyo Port and carries heavy ship traffic. To secure the passage of ships, temporary channels were established to avoid the construction area. Also, because a part of the breakwater that had an effect on the temporary channels was temporarily removed, a temporary breakwater was constructed farther out in the bay to secure calmness within the port.

(3) The tunnel was designed so as to be safe against even the strongest earthquake that is predicted for Tokyo Port. For example, flexible joints were used between each pair of tube elements to reduce the stress resultants that develop in the elements during an earthquake. Because the Great Hanshin-Awaji Earthquake occurred while this tunnel was under construction, its design was subjected to review. Through this review, the horizontal shear keys and the connecting cables were strengthened.

(4) In order to prevent damage to underwater tunnels due to fire, the Road Act provides that the passage of vehicles that carry a dangerous substance can be prohibited. However, because the Central Breakwater Reclamation Area is only accessible by tunnel, it was decided to allow the passage of vehicles carrying a dangerous substance by limiting the time of passage and requiring escort by a warning vehicle of the road management organization. Because of this, fire resistant plates that are capable of resisting a temperature of 1200℃ for 60 minutes were installed in the immersed tube elements so that the structure will not suffer serious damage even if a vehicle carrying a dangerous substance should catch fire. Also, in order to prevent simultaneous failure of illumination, communication and other systems due to fire, precautions such as providing double wiring circuits were taken.

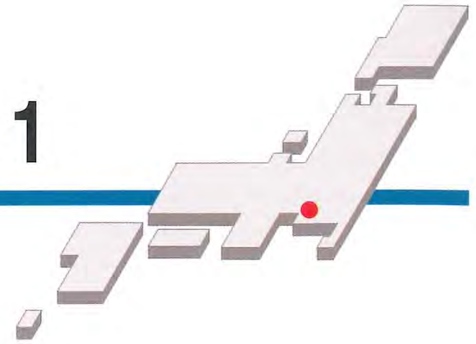
Location Map


Construction of Immersed Tube Elements (Dry-Dock)


Sinking of Immersed Tube Element


Interior of Immersed Tube Tunnel (During Construction)

Higashiyama Tunnel on Nagoya Expressway Route 1



Nobuaki SAITO
Director, Construction Division No.2,
Department of Construction,
Nagoya Expressway Public Corporation

Kazuhiro KANAMORI
Senior Engineering Administrator

The Nagoya Expressway Public Corporation is constructing and maintaining urban expressways located within Nagoya and connecting that city with the surrounding area.

Higashiyama Tunnel is a 2.6km long twin tunnel having two traffic lanes in each direction that is being constructed through a hilly area in the eastern part of Nagoya. The tunnels are being excavated by NATM.

The excavation cross section of these tunnels ranges in area from 120m² to 140m², the depth of cover ranges from 5m to 50m, and the distance between the centerlines of the two tunnels in the standard section ranges from 30m to 40m. Located at an elevation of 40m to 80m in hills that are generally high in the east and low in the west, Higashiyama Tunnel crosses this ridge in a generally east-west direction. The geology consists of unconsolidated Pliocene strata, called the Tokai Group Yadagawa Formation, that dip at three to four degrees from east to west.

The tunnel is being constructed by dividing it into five sections, each approximately 500m in length. Among the five construction sections, the work in Sonoyama Construction Section, located between Yotsuya Shaft and Higashiyama Ventilation Chamber, involved numerous difficulties due to its location beneath a major thoroughfare and a residential area for its entire length. The depth of cover was shallow, less than 1.5D (20m), the strata through which the tunnel was excavated are alternating strata of sand (Ps) and silty clay (Pc), and these are overlain by diluvial gravel (Dg). Each of these strata is unconsolidated, and the groundwater level was approximately 3m above the tunnel crown.

On the eastern side of Yotsuya Shaft, from which driving was commenced, an arterial highway of Nagoya City, together with numerous buried utility structures, crossed over the tunnel where the depth of cover was approximately 10m. Also, the two shield driven tunnels of Nagoya Subway Line No.4 crossed under Higashiyama Tunnel at a separation distance of 2.7m from the tunnel invert while the tunnel had its primary lining only.

Further, an old water main of 1100mm diameter was buried beneath the major thoroughfare that is located above the line of the westbound tunnel, and surface structures such as wooden houses and reinforced concrete apartment buildings were located above the eastbound tunnel. Thus, control of surface settlement was an important question in this construction section.

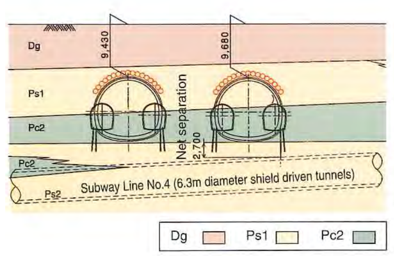
Because the tunnel face would not stand by itself in this water bearing condition, to control settlement, side pilots were driven, from which the groundwater level was drawn down by drainage boring as the excavation advanced, and, prior to excavation of the upper heading, the side wall concrete was placed with support by small diameter steel pipe (139.8mm) bearing piles.

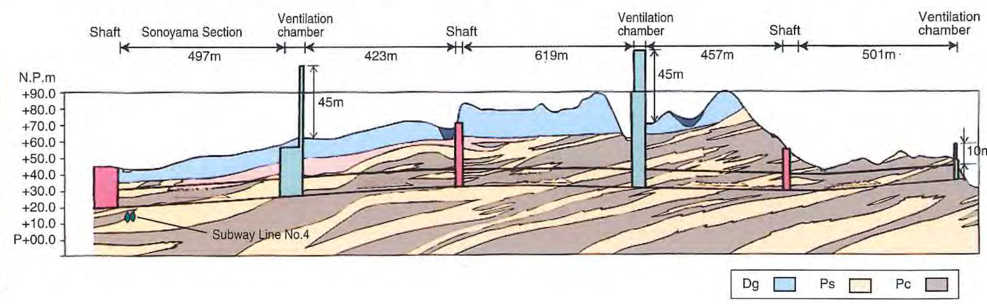
As protection for the upper heading, a pipe roof (800mm diameter, 80m long) was adopted at the highway crossing section just east of Yotsuya Shaft, and long pipe forepoling (114.3mm diameter, 18m long, 15m excavation shift length) was employed in other sections. Also, preload cells (bagged mortar) were placed behind the steel support ribs to control settlement.

Great difficulty was experienced in excavation of the side pilots due to inflow of groundwater. At first, urethane injection type forepoling and chemical grouting were used together to protect against collapse of the face and crown, but this was changed to the cost and schedule advantageous procedure of performing step injection of solution type grout material in the horizontal direction in the pilot arch area.

As a result of these measures, satisfactory control of settlement was achieved; the maximum amount of surface settlement being on the order of 25mm, and the maximum amount of settlement of the water main being 20mm (30mm allowable).

Construction of Higashiyama Tunnel is continuing at present toward the goal of full completion in the spring of 2002.





Construction of Suribachiyama Tunnel Rationalized by TWS

Toyomi YOKOO
Project Manager, Ohara Project Management Section, Tsuyama Construction Office, Chugoku Bureau, Japan Highway Public Corporation

Introduction

Suribachiyama Tunnel, located between Kuse and Yubara interchanges on the Yonago Expressway, is the longest highway tunnel (4099m in operation) in the Chugoku Region. The project of doubling Yonago Expressway from two to four lanes was commenced in FY1998. The construction at Suribachiyama Tunnel (Phase II length: 4088m) consists of widening the existing emergency tunnel, that parallels the Phase I tunnel, into a tunnel of full expressway cross section. Because the safety of persons who may need to use the emergency tunnel during construction must be secured, construction is being performed on only one face, from the south end. Because the construction period would be long if conventional construction methods were employed, a Tunnel Work Station (TWS), a multifunctional tunnel excavating machine, was adopted in an attempt to achieve rationalization of construction centered primarily on speedup and schedule shortening in tunnel excavation.

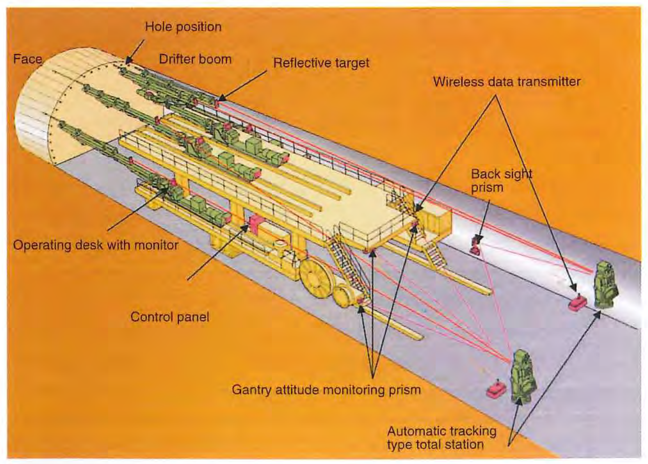
Construction Speedup by TWS

Suribachiyama Tunnel is being excavated by NATM by full-face excavation with a short bench using the method of drill and blast. TWS is equipped with four drill units, a shotcrete applicator, crane equipment and a drilling guidance system known as KIDS. Because the ground is in good condition so that the length of tunnel that will require installation of steel support sets is short, no devices have been provided for handling support sets.

KIDS is a system to assist high-speed working and reduction of overbreak in drill and blast operations in hardrock tunnels. This system is capable of efficiently assisting drilling operations by precisely detecting the positions of drill bits using automatic tracking type total stations located to the rear of the drill jumbo.

To decide the method of muck transport to be used, a comparative study was made regarding dump trucks, containers and a continuous belt conveyor system from the viewpoints of economy, environment and applicability, from which the use of containers was selected.

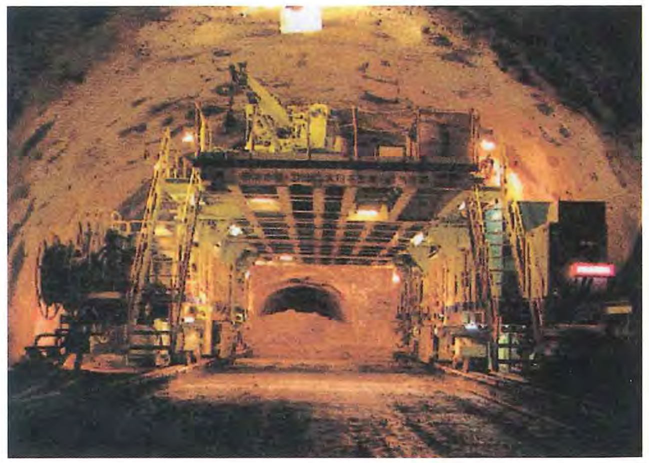
Drilling Guidance System



TWS Advantages

Since the start of excavation at the end of April 2000 up to the present time, approximately 3km of the total length of tunnel has been excavated, and good results are being obtained.

- Cycle time can be shortened and high speed excavation achieved because part of the time for interchanging equipment between operating cycles becomes unnecessary.
- By reducing the number of pieces of equipment at the tunnel face, the operating space can be rearranged and reduced, thus achieving improvement in both the operating environment and safety of operations.
- Because the position of the operator's line of sight is near the back holes and rib holes during drilling, the precision of horizontal hole drilling is high in comparison with conventional equipment.



Tunnel Widening without Closing to Traffic

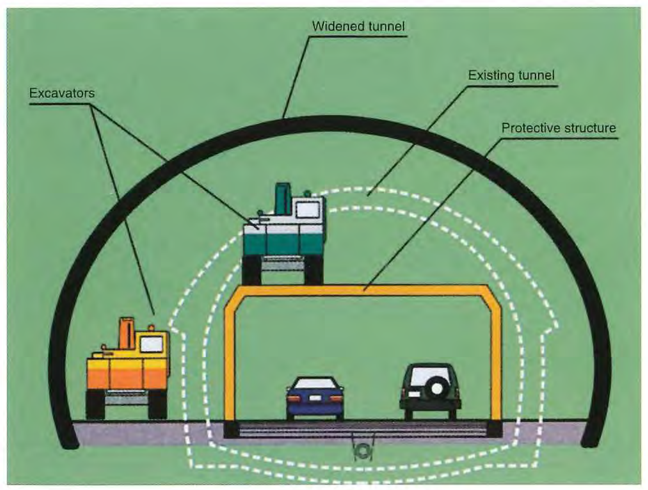
Yukio DOJO
Head of Section, Construction Division, Kitakyushu Office, Fukuoka-Kitakyushu Expressway Public Corporation

This project consists of widening a 170m long portal section of Okura Tunnel on Kitakyushu Expressway Route 4 from its existing two lane cross section to a three lane cross section to secure an acceleration lane that is required for a connection with Kitakyushu Expressway Route 5, a new highway that is presently under construction near the portal. Because Route 4 is an important transportation artery of the Kitakyushu urban area carrying a spot traffic volume of approximately 60,000 vehicles per day, it was necessary to maintain the two lanes of traffic during the tunnel widening construction.

Protective Structure

To protect the highway traffic from construction operations, it was decided to install a protective steel structure of 7.5m inside width and 4.15m inside height by which two lanes of traffic could be secured. The total length of protective structure was decided as 205m; 20m outside the portal, the 170m long section to be widened, and 15m beyond this section.

The protective structure was installed by assembling factory prefabricated parts in a temporary yard during the daytime and then moving it into the tunnel while traffic was stopped during the night. Because of the space available in the temporary yard, the length of structure that could be installed in one day was 12m. Other conditions affecting the installation work included the fact that the time available for nighttime operations was restricted to the seven hours between 22:00 and 5:00, the fact that the clearance between the existing tunnel lining and the shoulders of the protective structure was on the order of only about 5cm, and the fact that each 12m long section had a weight of 588kN. However, in spite of these severe conditions, by using a special large-model carrier vehicle, the full 205m length of protective structure was safely installed in 17 days.



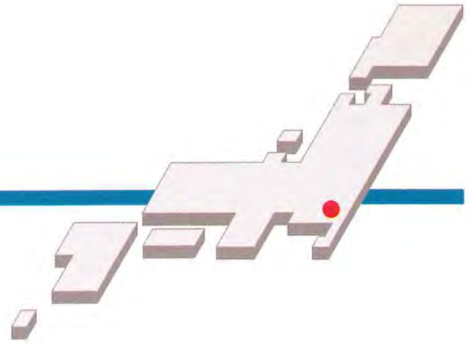
Tunnel Excavation

Excavation work was planned to be performed by parallel advance of upper heading excavation and bench excavation with the floor of the upper heading at the level of the roof of the protective structure. Because the excavation cross section has a large area of 155m² and is relatively flat compared to its width, a pipe roof was employed to secure stability of the tunnel crown in the first 80m section at the portal where the rock was in poor condition due to advanced weathering. Beyond this, the rock was sound with an unconfined compressive strength of 200 N/mm², so that excavation by hydraulic wedge was adopted. Because the bench is divided into two sides by the protective structure, excavation of these two sides was performed separately.

At the present time, work on the 170m long section of widening excavation has been completed. Following this, operations will continue in the order of secondary lining placement, invert formation and pavement placing, working diligently toward completion during FY2002. Among these, the method of performing invert formation, including the structure of the invert, while maintaining two lanes of traffic, is an important subject.

Section of Protective Structure

Shield Driven Tunnel for Water Distribution Main



Nobuyuki TAKIMOTO
Chief of Subsection No.2, Design Section No.2, Construction Division, Bureau of Waterworks, Tokyo Metropolitan Government

A water pipe bridge that crosses over Naka River, a river that flows through the eastern part of Tokyo, carries two water pipes, one of which is an 1100mm diameter riveted steel pipe constructed in 1923 and the other is a 1200mm diameter welded steel pipe constructed in 1931. Based on the results of a survey of the seismic safety and degree of deterioration of the bridge, it was decided to disuse this existing bridge and lay a new water distribution main of 1500mm diameter in a tunnel under the river to be constructed by the shield driving method.

Tunnel Alignment and Structure

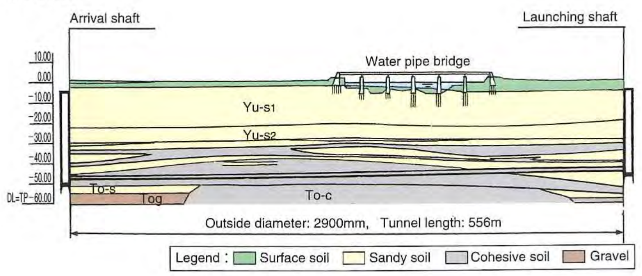
The tunnel has a total length of 556m, including the approximately 180m long section under the Naka River, and there is a sharply curved section of 14m radius near the arrival shaft. Because the ground in the project area consists of deep alluvial deposits of sandy soil and there is a great possibility that earthquake action may cause liquefaction in this soil to a depth of approximately 35m from the surface, the tunnel was located so as to pass through the underlying diluvial soil layers that chiefly consist of cohesive soil. The depth of cover ranges from 43m to 47m from the ground surface, and is approximately 37m from the deepest part of the riverbed.

A 1500mm inside diameter ductile cast steel pipe will be placed in the tunnel and the space between the segmental tunnel lining and the outside surface of the pipe will be filled with air milk. A preconstruction survey for combustible gas confirmed that the groundwater contains dissolved methane gas. Therefore, to secure cross sectional space for ventilation air supply and exhaust ducts that are necessary as a safety measure during shield driving, the segmental lining was designed to have an inside diameter of 2500mm (2900mm outside diameter). The shield machine, which has an outside diameter of 3040mm, is of the slurry type and is equipped with an articulation mechanism that is capable of a maximum deflection of 12°.

Shaft Construction

Due to restrictive site conditions and structural conditions, the shafts were designed to have a circular configuration with inside diameters of 9.5m at the launching shaft and 8m at the arrival shaft. Because both shafts have a depth exceeding 50m, caisson excavation was employed, an open caisson at the arrival shaft and a pneumatic caisson at the launching shaft. Because the maximum operating air pressure in this shaft construction would exceed 0.45MPa, a system of unmanned excavation by remote control was adopted for excavation below the depth of 20m. Further, because personnel enter the caisson for inspection once each day that excavation is performed, an air mixture (21% oxygen, 35% nitrogen and 44% helium) in which a portion of the nitrogen in natural air has been replaced by helium was used for respiration to prevent caisson disease when the pressure within the working chamber exceeded 0.3MPa.

Profile



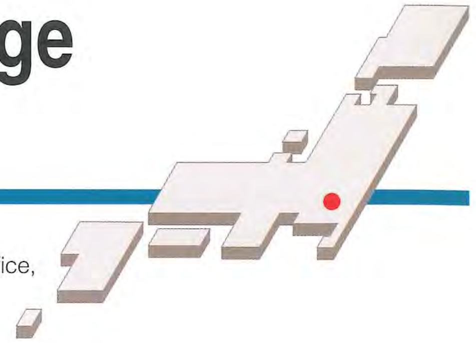
Method of Protection for Launching and Arrival

Because of the depth of the launching shaft, NOMST (Novel Material Shield-cuttable Tunnel wall system) was adopted as launching protection in the shaft wall. In the sharply curved section of the tunnel, ground improvement was omitted because the ground consists of diluvial cohesive soil. Instead, lining segments with inflatable bags were used in this section. By inflating the bags by injecting backfill grout material to fix them into the overcut cross section, ground reaction is obtained quickly and the flow of backfill grout material to the tunnel face is prevented. For protection at the arrival shaft, ground freezing was adopted because the shield machine arrives at the shaft in the articulated condition immediately after driving the sharply curved section. The necessary thickness of frozen ground was decided as 2m from the outside of the shield machine.

Primary Lining

Caisson Equipment at Launching Shaft

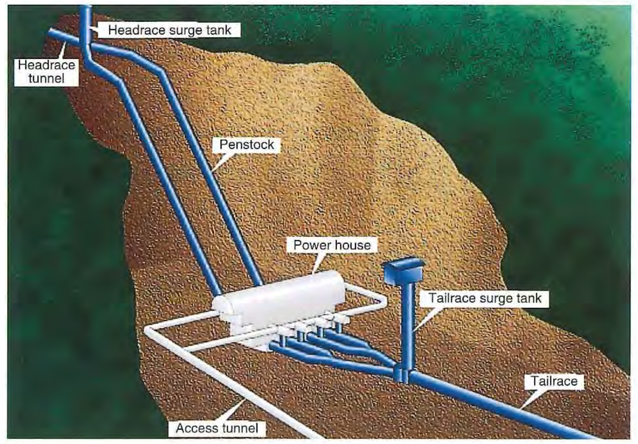
Large-Scale Pumped Storage Hydropower Station



Toshio MAEJIMA
General Manager,
Kannagawa Hydro Power Plant Ueno No.2 Construction Office,
The Tokyo Electric Power Co., Inc.

Kannagawa Hydropower Station is a pure pumped storage type hydropower station to have a maximum output of 2700MW (six 450MW units) which The Tokyo Electric Power Co., Inc. is presently constructing at a site in Gunma Prefecture northwest of Tokyo.

Two large-scale underground caverns are planned for this hydropower station. The 1800MW cavern that is now under construction to install four motor-generator units and two transformer units is 216m long, 33m wide and 52m high, and has a maximum cross sectional area of approximately 1400m^2 and a total excavation volume of approximately 220,000m^3. The excavation of this main cavern was begun in October 1998 and was completed in October 2000.



The geology at this site features a stratum belonging to the Chichibu belt of the Paleozoic-Mesozoic layer, which has a nearly east-west zonal structure and was redeposited by a submarine landslide of marine sediment in the Jurassic-Cretaceous period. This stratum consists of a chiefly pelitic matrix into which olistoliths of sandstone and chert are irregularly mixed. The powerhouse cavern is planned at a depth of approximately 500m within the rock mass where the maximum value of initial rock stress is as much as 12.5MPa.

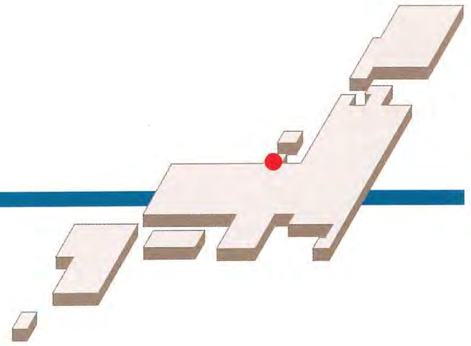
In the excavation of the cavern, observational construction management was performed, a technique by which monitored data that is obtained during construction is processed and fed back into construction. Owing to the rapid development of Information Technology including heightened computer capability and enrichment of software, the observational construction management system has become capable of quicker response. Also, in order to perform observational construction management of high precision, it is important to accurately grasp the state of development of the zone of loosened rock within the surrounding rock mass due to cavern excavation and appropriately predict the subsequent behavior of the rock mass on further cavern excavation. Therefore, at this site, observational construction management was performed by carefully monitoring the zone of loosened rock. In addition to monitoring the amount of strain by conventional means such as borehole extensometers, absolute stress around the cavern was measured by Compact Conical-ended Borehole Overcoring during excavation, and variation in the state of stress around the cavern was continuously monitored by means of acoustic emission sensors and vibrating wire stress meters installed in the rock. Also, improvement was achieved in the precision of locating planes of discontinuity by developing a system to include logging of PS anchor boreholes in the excavation cycle to grasp further information on geological conditions around the cavern. As a result, it was possible to optimize the support design by evaluating the effect of planes of discontinuity around the cavern and correcting the predicted model during excavation.

Further, to positively control loosening that develops in the rock around the cavern accompanying excavation, the effect of PS anchors was evaluated by predictive analysis and anchors were arranged in concentrated layout in zones of stress concentration where they were considered to be effective. Also, the 3-dimensional restraining effect of rock struts was evaluated and reflected into support design. In addition, to relieve stress concentration at inside corners and realize the restraining effect of rock struts to a maximum, curvature was given to the excavated configuration of the inside corners of the generator chamber, thus achieving further optimization of the support design.

Bench excavation (No.4 bench)

Bench excavation (at completion of No.11 bench)

Undersea Tunnel for Nuclear Power Plant



Tetsuro NAKAGAWA — Deputy General Manager,
Shika Nuclear Power Plant Construction Office,
The Hokuriku Electric Power Co., Inc.

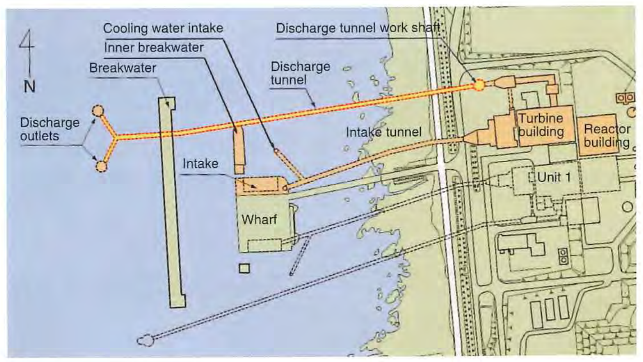
Shika Nuclear Power Plant Unit 2, located on the west coast of the central part of Noto Peninsula, is a 1358MW capacity ABWR (Advanced Boiling-Water Reactor) type nuclear power unit that is presently under construction by The Hokuriku Electric Power Co., Inc. with March 2006 as the target date for beginning operation.

Seawater will be used for the cooling water that is required at a rate of 93 m^3/s for operation of the generating unit. The intake and discharge facilities for this seawater were designed as undersea tunnels to protect the environment during construction and reduce the range of diffusion of warm discharge water.

The ocean floor has very uneven reef topography with a slope of approximately 1/30 toward offshore. The geology consists of andesite and tuff breccia, and the andesite has numerous joints in part. The average unconfined compressive strength of the rock ranges from 15 N/mm^2 to 150 N/mm^2, and the coefficient of permeability is on the order of 10^{-3} cm/s to 10^{-4} cm/s.

The intake tunnel is approximately 400m long and has an inside diameter of 6.8m. The discharge tunnel consists of a main tunnel that is approximately 730m long with a 6.8m inside diameter and two branch tunnels that are each approximately 80m long with a 4.8m inside diameter.

In determining the methods to be used in constructing the undersea tunnels considering the severe conditions of (1) a large excavation cross section of approximately 8m diameter, (2) widely varying rock strength, and (3) high water pressure of approximately 0.6MPa, various methods were studied from the viewpoints of technical applicability, economy and time schedule. From these studies it was decided to employ a slurry type shield machine designed for rock in the discharge tunnel, which is long, and NATM with grout injection for water sealing in the intake tunnel.



The shield machine has several special features. (1) Because a supplementary operation such as grout injection for water sealing is required in order to replace disc cutters, an attempt was made to reduce the number of replacement operations, and thus save construction time and cost, by employing 19 inch disc cutters, for the first time in Japan, and using cold worked die steel in the cutter rings to improve their durability and wear resistance. Also, disk cutter wear detectors were provided to monitor the amount of wear. (2) To cope with the widely varying rock strength, the machine was equipped with 22 thrust jacks of 2940kN capacity and 10 electric motors of 150kW rating to drive the cutter face at a speed of revolution that could be varied to four speeds between 1.5rpm and 4rpm. (3) To cope with the high water pressure, a three stage tail seal of wire brush type was provided.

Cotter and quick joint segments were employed in the tunnel lining, a type in which loss of concrete cross section and exposure of metal joint components is small, and a secondary lining was omitted. Also, labor saving was achieved in segment erection by employing a semi-automatic erector in which the actions from grasping to rough positioning were automated.

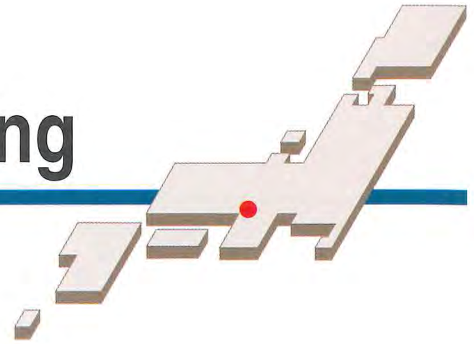
The excess slurry that was generated as tunnel driving advanced was treated by adding cement and performing vacuum pressure dehydration to secure dehydrated cake of the required strength and this was effectively utilized as fill material and backfill material within the power station site.


Slurry Type Shield Machine Designed for Rock

Shield driving in the discharge tunnel was commenced in June 2000. As a result of performing fine control of driving speed, disk cutter penetration, thrust on the cutter face, cutter torque and other factors, driving progressed smoothly without any replacement of disk cutters so that driving of the main tunnel was completed in January 2001, and dismantling of the shield machine was completed in March. As of December 2001, the branch tunnels were being excavated by NATM with grout injection for water sealing.


Cotter and Quick Joint Segment

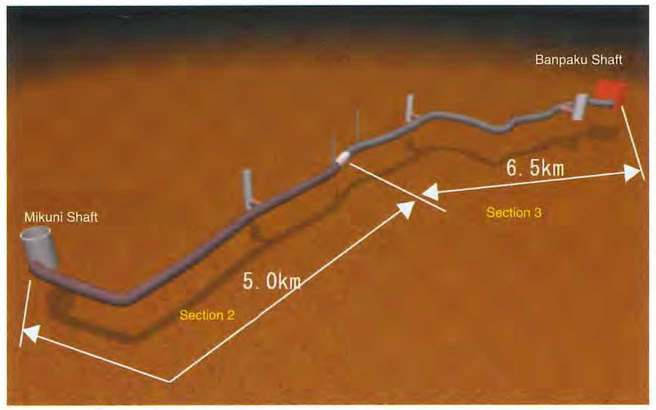
Japan's Longest Long-Distance Shield Driving



Kazutoshi UMEDA — Deputy General Manager,
Transmission and Substation Construction Office,
The Kansai Electric Power Co., Inc.

Hitoshi FUKAMI — Underground Lines Civil Engineering Section

The Kansai Electric Power Co., Inc. is in the process of constructing underground transmission line tunnels to supply 500kV electricity to the central area of the city of Osaka. In the approximately 11.5km long section of these tunnels between Mikuni Shaft and Banpaku Shaft, extra long-distance driving was performed at high speed by 5750mm diameter slurry type shield machines for distances of 5.0km and 6.5km respectively in Construction Sections 2 and 3, and the two machines were made to dock together within the ground where they met. These distances are without precedent in Japan. One of the principal technical problems in this project concerned the durability (measures against wear) of the cutter bits that is indispensable for long-distance driving. A report concerning the construction technology of this project was presented in the 2000 edition of *Tunnelling Activities in Japan*.



Geology

The soil through which the tunnel was driven in Construction Section 2 consisted of alternating layers of sandy and cohesive soil of the upper and lower members of the Osaka Diluvium, including gravel layers in part. The maximum depth of cover was approximately 50m with high groundwater pressure. In Construction Section 3, the tunnel passed through alternating layers of sandy and cohesive soil of the lower member of the Osaka Diluvium. The maximum depth of cover was approximately 45m and the soil was for the most part in an unsaturated condition.

Shield Driving

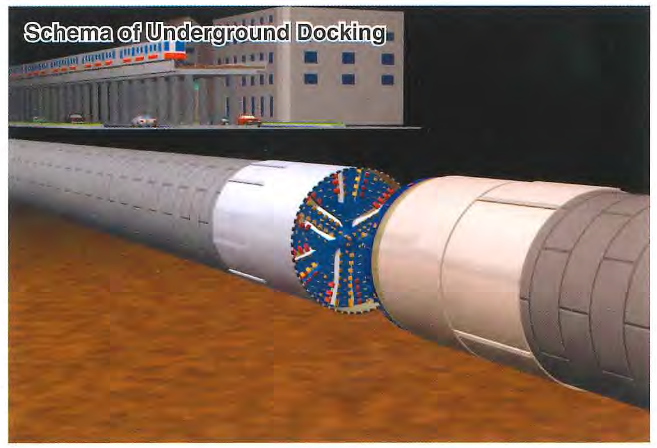
Shield driving commenced in July 1998 in Construction Section 2 and March 1998 in Construction Section 3, and ended with the completion of underground docking in August 2000. In Construction Section 2, the maximum daily advance was 24m, the maximum monthly advance was 376m, and the average monthly advance during main driving was 309m. In Construction Section 3, the maximum daily advance was 22.8m, the maximum monthly advance was 431m, and the average monthly advance during main driving was 292m. The time required for one 1.2m wide lining ring was the same in both construction sections, 20 minutes for excavation and 25 minutes for erection.

Cutter Bit Wear

The measures that were taken against wear of cutter bits were adoption of extra hard chips of even greater hardness, enlargement of the size of the chips, and provision of a bit exchange system (exchange bits built into the cutter head). The results of measurement of wear following dismantling of the shield machines were compared with initial estimates of amount of wear that were computed by multiplying wear coefficients by the distance of travel through each type of soil. The measured amount of wear in Construction Section 2 was within the estimated amount, but that in Construction Section 3 was approximately twice the estimated amount. It is thought that factors such as the character of the soil (unsaturated or saturated) had a major influence in producing this difference, and this needs to be reflected back into future design.

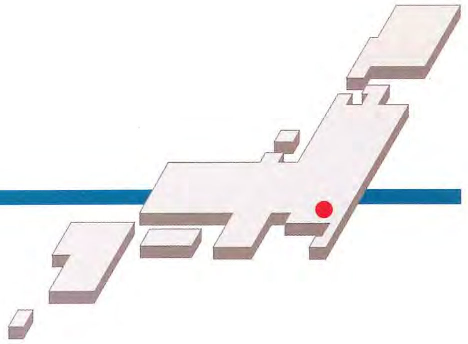
Underground Docking

The precision required in docking after the long-distance driving was axial deviation within 30mm and a lap distance of 150mm or more. Near the point of docking, the positions of the two shield machines were confirmed by means of vertical boring from the ground surface, and by performing strict control of final driving, underground docking was achieved with high precision.


Schema of Underground Docking


View of Tunnel Face after Underground Docking

Ultra-Large Cross Section Tunnel Regulating Pond



Koichi IRIYAMA
Counselor, Kawasaki River Improvement Office, Kanagawa Prefecture

Tsurumi River is a first class river that has its source in Kamioyamada-machi of Machida City in Tokyo and flows through the cities of Kawasaki and Yokohama to its mouth into Tokyo Bay. The river is 42.5km long and has a drainage area of 235km². As a result of the concentration of population and property accompanying the rapid development and urbanization of the Metropolitan Region, the retention and retarding functions in the drainage area have markedly declined so that safety against flooding has become difficult to secure.

Onmawashi Park Regulating Pond is an underground facility of approximately 110,000m³ capacity that was constructed as a tunnel utilizing underground space beneath Onmawashi Park (formerly the riverbed of Tsurumi River) as a part of the comprehensive conservancy plan for Tsurumi River. The regulating pond will cut the peak river flow by 42.7 m³/sec.

The regulating pond consists of an intake shaft, the main tunnel, and a connecting structure. The main tunnel, which has an ultra-large cross section (254.1m²) that is one of the largest in Japan, was to be constructed in Quaternary mudstone that underlies a sand layer containing confined groundwater beneath a densely built-up urban area.

Because this was an urban tunnel of ultra-large cross section that had never before been constructed in soft rock, numerous unknown factors were involved such as displacement and deformation of the surrounding rock and tunnel support during excavation, and stability of the tunnel crown beneath a sand layer that contains confined groundwater. Therefore, the following points were raised as problems in construction.

(1) There was very little past experience in the construction in mudstone of a tunnel of ultra-large cross section, one of the largest in the country, that had dimensions of 17.2m in width, 18.2m in height and an excavation cross section of 254.1m².

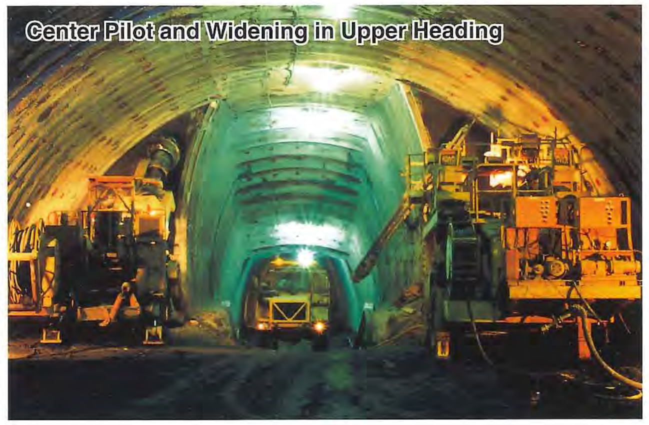
(2) With numerous houses being located on the ground surface adjacent to the site, restrictive conditions regarding surface settlement were severe.

(3) Because the mudstone was overlain by a layer of unconsolidated sand containing confined groundwater and there was a great possibility that the development of loosening in the mudstone due to excavation would cause flow and progressive breakdown of the ground, settlement and loosening in the mudstone had to be controlled to the utmost.

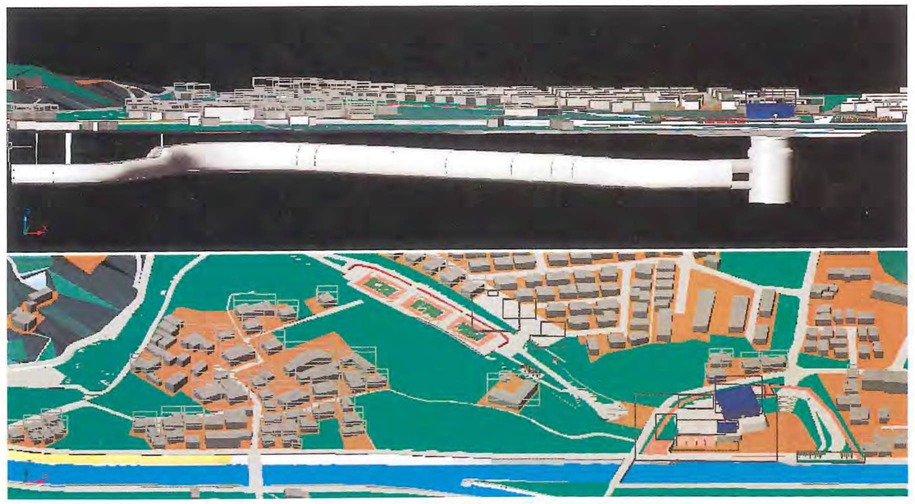
In selecting the method of excavation to meet these problems, verification was obtained by performing numerical analysis and test construction to accurately predict the behavior of the surrounding ground and surface displacement. The method of excavation that was thus selected was to drive a center pilot in the upper heading, widen this out to full tunnel width, and then perform bench cut excavation.

It is believed that this project, in which a tunnel of ultra-large cross section was excavated by NATM in soft rock beneath a layer of unconsolidated sand containing confined groundwater located within an urban area, was an important project that shows a model for the efficient utilization of deep underground space in the future.

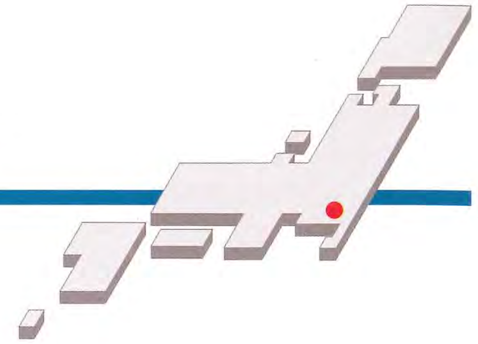
Construction of this tunnel was commenced in November 1998. Excavation was completed at the end of March 2000, and all work was safely completed at the end of March 2001.



Center Pilot and Widening in Upper Heading



Regulating Pond Beneath National Highway



Hiroshi OHGIHARA
Manager, River Design Division, River & Canal Department, Sewage Works Bureau, City of Yokohama

Imai River, approximately 7km long with a drainage area of 7.6km², is an urban river that has its source in the hills of Hodogaya Ward of the City of Yokohama. Urbanization has advanced rapidly in the river's drainage area since about 1960, to the extent that it had reached approximately 80% in 2000. As a result, forest and agricultural land have been lost to a great extent, runoff into the river has increased, and lowland areas have suffered major flood damage numerous times. Because of this, drastic flood control measures have been demanded, but both banks of Imai River are densely built-up with houses and stores, making land acquisition extremely difficult. Also, because there is absolutely no vacant land in the upper and middle reaches of the river that is suitable for locating a natural flow type retarding basin, it was decided to construct a storage facility in the form of a tunnel beneath National Highway Route 1 for the temporary storage of floodwater.

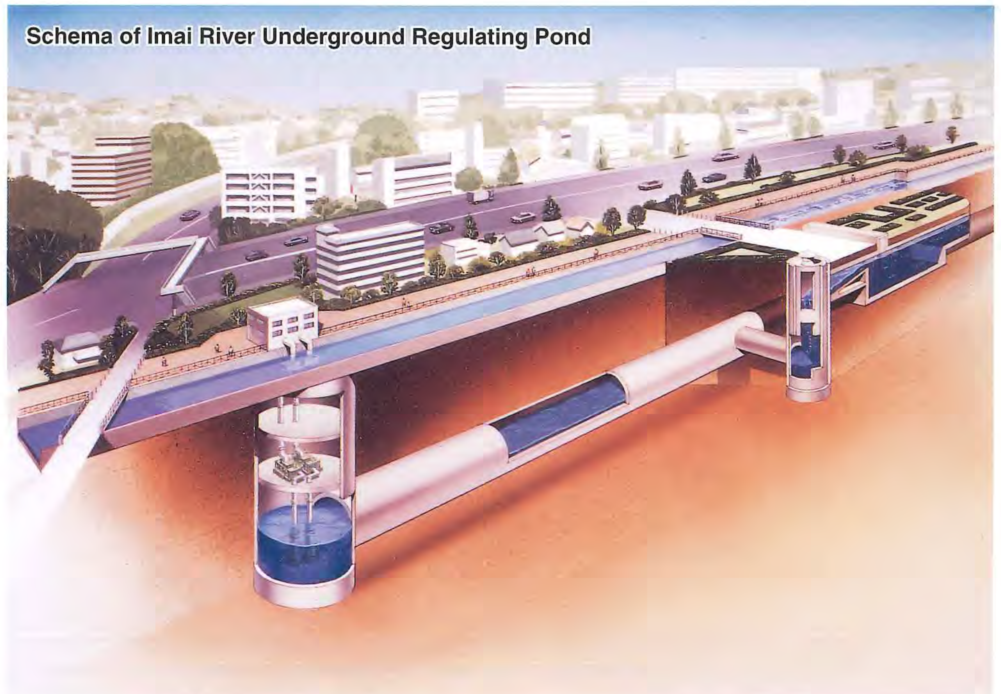
Assuming that a one hour rainfall of 82mm will occur with a probability of once in 50 years, it was decided to construct a facility having a storage capacity of 178,000m³. Considering various factors including the width of the highway and its alignment, a decision was made to construct a 2000m long shield driven tunnel of 10.8m finished inside diameter at a depth of 60m to 80m.

In addition to the shield driven tunnel that forms its main body, this underground regulating pond also includes an intake facility, a drainage pump facility and other structures, each of which involved difficult construction performed under unprecedented conditions of depth and high water pressure.

At the launching base for the shield machine, a 62.0m deep shaft was constructed within a 93.1m deep diaphragm wall, working under the conditions of a confined urban site. Driving of the tunnel was performed under a water pressure of 0.75MPa, one of the highest in Japan, at a depth of cover that reached a maximum of 85m, and involved long-distance driving of 2000m including sharp curve driving with a short radius of curvature of 130m. For this high water pressure and sharp curvature, an articulated slurry type shield machine (12.14m o.d.) was employed, a machine that possesses confirmed durability and water sealing performance. In the concrete segmental lining, metal bolt box connections were used which were designed to achieve higher joint rigidity and reduced leakage through joints. Also, by employing a segmental lining that was designed to resist internal pressure, a secondary lining was omitted, thus achieving cost reduction and shortening of construction time.

The intake facility is connected to the regulating pond by means of a 15m long, 4.0m i.d. connecting pipe, the construction of which involved tunnel excavation under water pressure of 0.49MPa at a depth of cover of 50m. Because of this, a pipe roof was employed surrounding the whole circumference of the pipe.

Construction was commenced in FY1993, and with the development and introduction of new technology at the several construction sites, shield driving was successfully completed in July 2000. Following that, work such as connection of the connecting pipe and construction of the intake facility was completed at the end of March 2001, making possible provisional use. Completion of all facilities and commencement of genuine operation are scheduled for spring of 2004.



Schema of Imai River Underground Regulating Pond

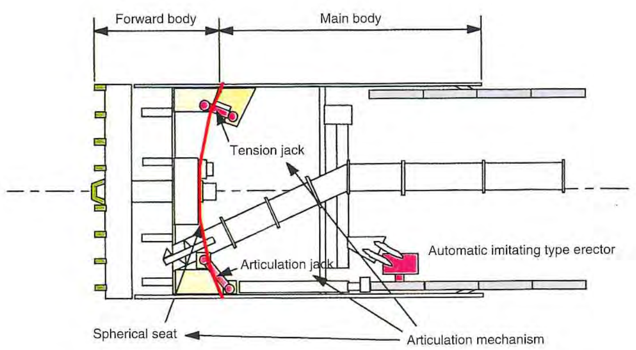
Innovations in Technology

F-NAVI Shield Tunneling Method

A notable tendency to be seen recently in shield driven tunneling is lengthening of the distance to be driven by one machine resulting from difficulty in securing sites for shafts and demand for overall cost reduction. Together with improvement in shield machine durability, another measure in this direction that is in strong demand is further speed-up of operations to achieve shortening of construction time. One method of achieving this is simultaneous performance of driving and segment erection.

"F-NAVI Shield Tunneling Method" is the abbreviation of Front-NAVIgate Shield Tunneling Method, which means that the forward body guides the shield machine in the correct direction. The shield machine is divided into a forward body that is equipped with the excavating cutter mechanism and the main body that is equipped with the thrust jacks that are the driving mechanism for forward excavation movement. The forward body is joined to the main body through a newly developed spherical seat that allows it to move in any direction and connecting jacks. During excavation driving, the attitude of the shield machine is controlled by actuating the connecting jacks so that the direction of the forward body is constantly on the planned line. Because operations are separated, i.e., direction control by the forward body and driving by the thrust jacks in the main body, driving and segment erection can be performed simultaneously. In this way, the F-NAVI Shield Tunneling Method has realized speed-up of operations in that the shield machine "is constantly advancing."

Achievements that have been attained in applying the F-NAVI Shield Tunneling Method are maximum daily advances in the range of 24m to 26m and maximum monthly advances in the range of 504m to 526m. By applying this method, construction speed can be obtained that is two to three times that obtained by conventional method, realizing substantial shortening of construction time and reduction of cost. (Shimizu Corporation)



Backfill Shield Method

The space beneath the streets of Tokyo and other large cities is crowded with underground structures that sometimes become an obstruction in route selection when planning new, large-scale underground structures such as an expressway.

Up until now, the method generally used in removing an existing structure has been open cut excavation. The "Backfill Shield Method" that is introduced here is a new shield excavation technique by which an existing shield driven tunnel can be removed and the resulting cavity simultaneously backfilled without making an open cut.

The shield machine, which is of the slurry type, has a cylindrical configuration to surround the existing tunnel and a double shield structure consisting of a forward shield and a rear shield. The sequence of operations is as follows.

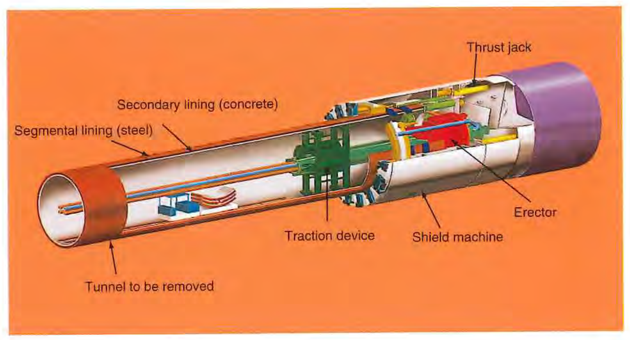
(1) As a preparatory step, thesecondary concrete lining in the tunnel is broken out by roadheader and removed.

(2) After assembling the shield machine, the forward shield is advanced by extending the thrust jacks while the ground surrounding the tunnel is excavated.

(3) While pulling the rear shield forward by means of traction jacks, the cavity behind the machine is filled by injecting backfill material that has high initial strength and small shrinkage.

(4) The bolts connecting the steel segments are removed and the segmental lining is dismantled one segment at a time by the dismantling "erector."

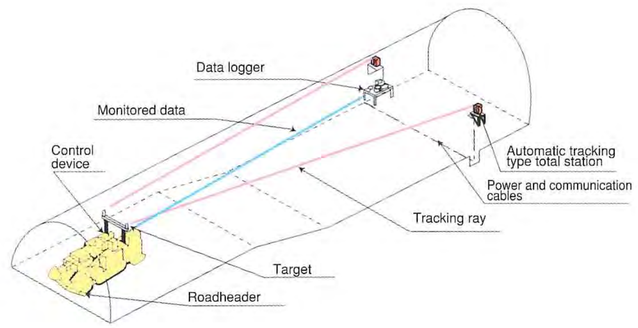
The project on which this technique is being employed is the removal of an existing communications cable tunnel that is an obstruction to the construction of a shield driven tunnel on the Metropolitan Expressway Central Circular Shinjuku Route. A shield driven tunnel of 3.25m outside diameter that has a steel segment lining will be removed for a distance of approximately 1km. This backfill shield machine is scheduled for launching in early 2002. (Metropolitan Expressway Public Corporation)



NARAI Excavation System

This is a system to control in real time the three-dimensional coordinates of the cutting drum of a roadheader to excavate along the line of the set tunnel cross section with high precision on the order of ±5cm without being affected by the degree of operator skill. Besides being able to reduce construction cost by avoiding excess muck handling and lining concrete, a ground assistant to confirm the condition of the face and give directions during excavation becomes unnecessary, thus contributing to improved safety and efficiency. This system is composed of the following three systems.

- Position Detection System: Two automatic tracking type total stations are set up to the rear of the face to detect in real time the position and direction of the base of the roadheader as it moves.
- Excavation System (Numerical Control System): The three-dimensional coordinates of the cutting drum are computed by detecting the attitude angles and amount of boom movement of the roadheader and combining this data with the data of base position. The system has a function that automatically stops the boom and locks movement in the direction of over-excavation when the boom seems about to enter a condition of over-excavation exceeding the determined cross section due to error by the operator.
- Laser Marking System: By adding to the total station a laser marking function to indicate the position for support erection corresponding to the position of the face, laser devices that have been set up separately in the past can be dispensed with. (Advanced Construction Technology Center)

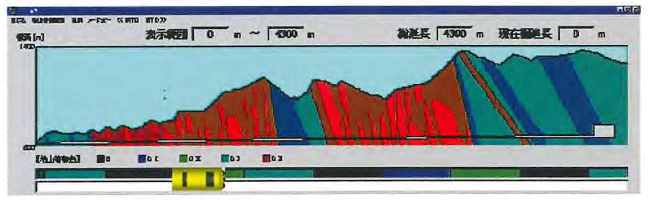


TBM Excavation Control System

Because the face can not be observed during TBM excavation driving, trouble such as binding of the machine has often occurred in geologically complex ground like that of Japan, and the high-speed driving performance inherent in a TBM has not been satisfactorily obtained. For this reason, the TBM Excavation Control System (TBM Navigator) was developed for the principal objective of grasping quickly and precisely in real time the geological conditions ahead of the face and surrounding the machine. This system collects mechanical data from the TBM during excavation, and from this collected data computes in real time items of data such as rock strength and energy per unit of excavated volume that indicate geological conditions. Also, by recording other data such as that which is obtained from logging of the drilling that is performed continuously in advance of excavation for the purpose of advance exploration, the geological profile that was predicted in advance can be successively revised while the excavation is being advanced. Further, by measuring the weight of muck and analyzing digital camera photographs of the condition of the excavated wall and the grain size distribution of the excavated muck, geological conditions are confirmed and fed back into the results of geological prediction.

Alignment control of the TBM can be performed visually by obtaining surveying data of high precision in real time by combining data from automatic tracking type total stations with data from a gyrocompass. The system also has a function by which all operation information is clearly shown and tabulated in correlated form.

There is also a system for supervision by watching the support operation at the machine tail, the tunnel wall surface and the condition of the muck on the belt conveyor by video cameras, and transmitting these images and the mechanical sounds of the TBM to the TBM operation room and the control room on the surface. (Kajima Corporation)



Innovations in Technology

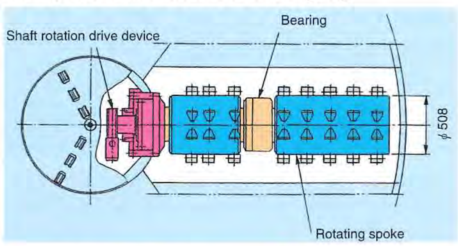
Spoke Rotation Bit Changing

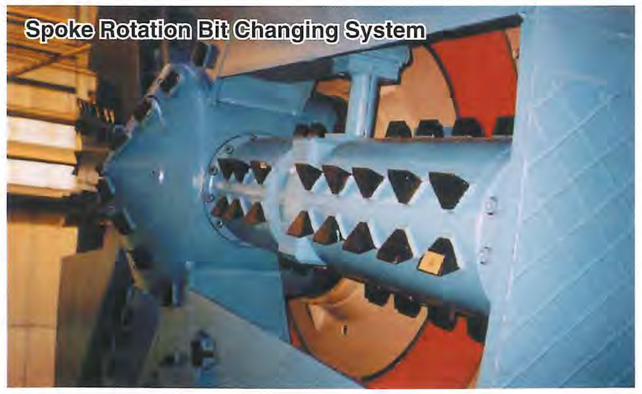
In recent years, there are an increasing number of shield driven tunnel projects in which changing shield machine cutter bits becomes necessary due to extended length of driving or excavation through ground such as sand and gravel that causes intensive wear. The method that has generally been used in changing these bits has been either to improve the ground ahead of the shield machine face and have workers go out ahead of the machine face to change the bits, or to construct a shaft for changing the bits, but both methods have been costly and time consuming, and there has been anxiety about safety.

Kajima took up the challenge of developing a method by which bits could be changed easily from within the shield machine and has achieved practical use of "Spoke Rotation Bit Changing." By structuring the cutter spokes so that they can be rotated about their own axes and mounting spare cutter bits on the spokes in three lines at 120° spacing about the spoke axis, spare bits can be moved around to the face by rotating the spokes as required to replace worn bits. Because rotation of the cutter spokes is performed by a hydraulic drive device that is operated from within the shield machine, a special apparatus is not required. Also, because this system is simple in structure, it can be installed on an ordinary shield machine, either slurry type or EPB, at low cost.

The increase in shield machine cost due to adopting this system is on the order of 10% to 20% of the cost of the main machine, but because the bit changing operation can be performed simply and in a short time, and also without any need for ground improvement or other additional work, this system is superior in terms of the overall cost and construction period of a project. (The Tokyo Electric Power Co., Inc., Kajima Corporation and Kawasaki Heavy Industries, Ltd.)

Schema of Spoke Rotation Bit Changing

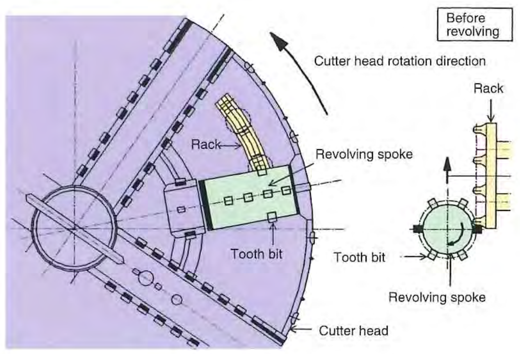


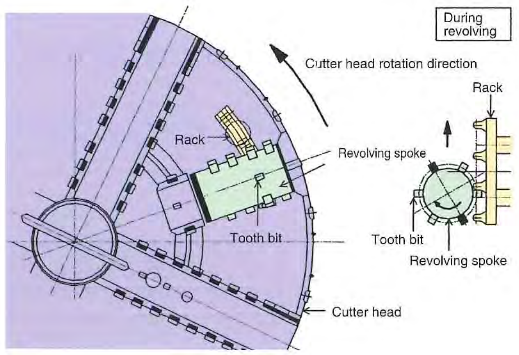


Revo-Bits System

In shield driving work over a long distance or through gravel, it often becomes necessary to change cutter bits due to advanced wear. In the past, bit changing has been performed either within a shaft constructed for that purpose, or by first performing ground improvement or other soil treatment to secure face stability and water cutoff followed by workers passing through an air lock to enter the space ahead of the cutter face to change the bits by hand. However, because such methods often entail danger in working within a narrow space, in addition to the fact that considerable time is required, methods for changing bits mechanically have been in demand.

"Revo-Bits System" is the abbreviation of "Revolving cutter Bits System" that signifies a method of changing cutter bits by revolving the shield machine's cutter spokes. In this method, the reserve bits are installed on the back of the cutter spokes and these reserve bits are interchanged for the worn bits by revolving the spokes. This spoke revolving is performed by engaging a rack that is attached to the bulkhead with teeth that are attached to the spokes and then rotating the cutter head. Thus, a special characteristic is the fact that separate power is not specially provided for revolving the cutter spokes, this power being provided by the motors for driving the cutter head. A 7.2m diameter EPB shield machine that was used in railway tunnel construction was equipped with this system, and the time required to revolve one spoke within the ground was 23min. A trial computation of possible driving distance judging from the state of bit wear on this project shows that by adopting the Revo-Bits System, a distance can be attained that is approximately 1.6 times that generally attained. (Shimizu Corporation)





Relay Bit Method

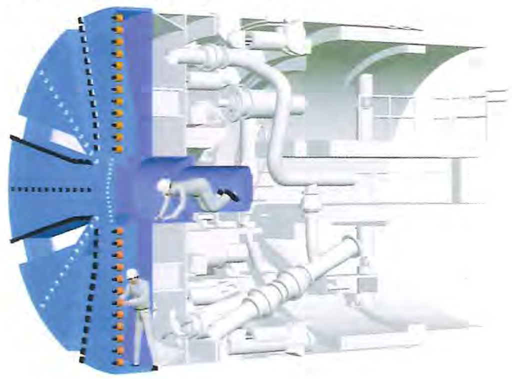
In response to the trend for cost reduction in recent years, the length of driving required in shield driven tunnel construction is becoming longer and various tries are being made to achieve this, but none of them have been satisfactory in the aspects of cost and construction schedule. One category in which new technology is necessary for lengthening shield driving distance is that of techniques for changing cutter bits, which become worn down during excavation. The method of changing bits that has been employed up to now has been either to construct an intermediate shaft for changing bits or to perform ground improvement ahead of the face and have workers go out in front of the cutter disk to change bits.

As a first solution, Spoke Rotation Bit Changing was developed as a mechanical method of changing cutter bits that does not require ground treatment. Following this, the "Relay Bit Method" was developed and put into practical use as a method of changing cutter bits without limitation on the number of changes.

A special characteristic of this new method is the fact that bits can be changed any number of times without performing ground treatment and without having workers enter space ahead of the cutter disk. Another is the fact that bits can be changed at any time and location without any need for restriction. The Relay Bit Method is a simple method in which space that is sufficient for workers to enter is provided within the spokes of the cutter disk and workers enter this space from within the shield machine to change the bits one by one. The bits are enclosed in cylindrical cases that are fitted with special ball valves that are turned to maintain tightness against water so that the bits can be changed. Not only can the state of wear and damage to the bits be directly confirmed by sight, but bits can be changed as needed to suit the type of soil to be excavated. Another possible use is to change bits to a suitable type when a NOMST wall is to be cut through.

By mounting Relay Bits, the cost of a shield machine is somewhat increased (approximately 15% to 20%, although this varies depending on factors such as machine diameter), but trial calculations show that total construction cost is reduced in comparison with conventional methods.
(Kajima Corporation)

Schema of Relay Bit Method



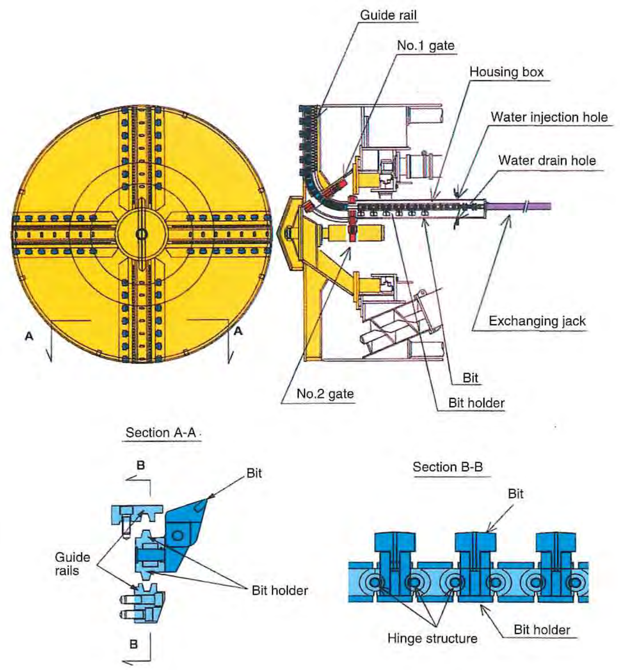
Trail Method

Long-distance driving at great depth is in demand in shield driven tunnel construction. The durability of cutter bits must be solved in order to establish methods for such work, but there is a limit to the durability of bits in excavating various types of soil over a long distance.

The "Trail Method" Shield Machine Cutter Bits Exchange System is a system for mechanically exchanging bits that has solved these problems. Bits are pulled into the interior of the shield machine by sliding the bit holders that grasp the bits along guide rails that are fixed on the cutter face spokes and then pushing them back out again after exchanging to new bits.

The special characteristics of the Trail Method are as follows. (1) Efficient long-distance shield driving is possible because the bits can be exchanged several times. (2) Also, because bit exchanging can be performed easily and in a short time, bits can be exchanged to a type of bit that has good excavation efficiency in the type of soil to be excavated. (3) The structure of the bit exchanging mechanism is simple and can be adapted to various methods, and the spoke shape is no different from that of conventional machines. (4) Because special soil treatment for ground improvement is not necessary, bit exchanging can be performed safely from within the shield machine at any location without any need for selection.

As described above, a low-cost bit exchanging system has been built. As an achievement in practical use, the reliability of this bit exchanging system was confirmed through demonstration construction at the Egawa Area Storm-water Main for the city of Kawasaki. Also, the system is presently in use in shield driving (3500mm excavation diameter for a distance of 2416m) for the Tokyo Metropolitan Government Bureau of Sewerage. (Tobishima Corporation)



Innovations in Technology

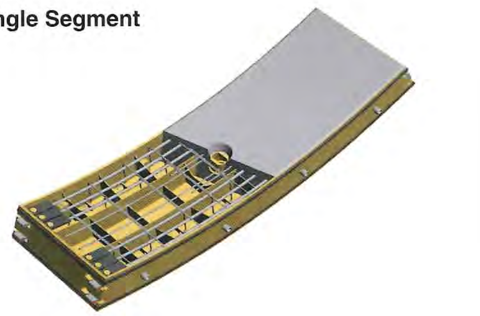
DRC Segments

Accompanying the advance of urbanization in Japan, flood damage due to localized torrential rainfall has become a problem in recent years. The control of flooding by constructing an underground river to utilize its retarding function is effective in alleviating such damage, and qualities such as resistance to high internal water pressure, corrosion resistance and inside surface smoothness are sought in these underground river tunnels.

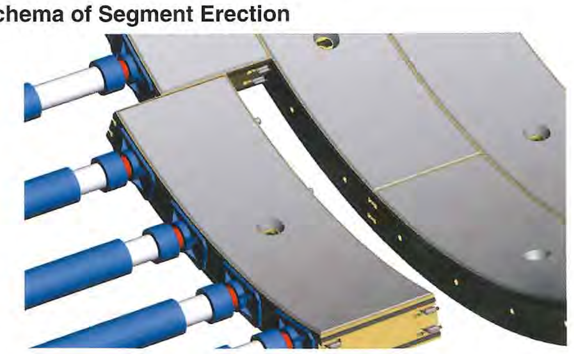
The newly developed "Ductile and Reinforced Concrete Segment" lining is an optimum lining material for these underground rivers. The most advanced technology has been incorporated into the structures of both the segments themselves and their joints. A composite structure composed of ductile cast steel, concrete and reinforcing steel has been realized in the segments. Due to the high strength and stiffness of a composite structure, the lining can be reduced in thickness, thus achieving a reduction in excavation cross section. (In a tunnel of 12m diameter, the excavation cross section is reduced by 5% to 7% compared to concrete segments.)

Also, joints that employ completely new concepts of joint structure, "AS Joints" and "Anchor Joints," have been adopted. Because joints can be completed merely by pushing the segments into place using the thrust jacks, these joints are adaptable to high-speed erection and automatic erection. Further, because these joints have structures that do not require bolt boxes, a tunnel having a smooth inner surface and a high degree of durability can be secured merely by using this primary lining alone, and a secondary lining is not required. These DRC Segments are to be used in Construction Section 4 of the Metropolitan Area Outer Discharge Channel. (Kubota Corporation)

Schema of Single Segment



Schema of Segment Erection



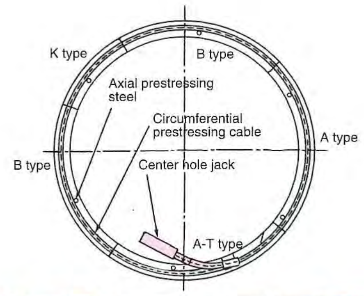
P&PC Segmental Lining

"Prestressed Precast Concrete Segmental Lining" is a new type of segmental lining in which prestress is introduced in the circumferential direction of the tunnel by inserting steel prestressing cable into sheaths, which were imbedded in the concrete segments during their manufacture, and then stressing and anchoring the cable, performing these operations from inside the tunnel after each ring of segments has been erected. Because unbonded steel prestressing cable, which has little friction loss, is used, sufficient prestress can be introduced by stressing at one location in each circumference. As the anchoring fixture, X-shaped Anchoring Device, which is easy to install in segment manufacture, is imbedded in the segments.

The special characteristics of this segmental lining are as follows.

- By making the segment ring into a prestressed structure, the lining will not crack and it acquires superior qualities of true circularity, water cut-off and durability.
- Overall cost reduction is possible due to the reduction of outside tunnel diameter achieved by omission of metal joint fixtures, simplification of reinforcing steel, omission of secondary lining, and reduction of thickness.
- Construction is made easier because the operation of bolt tightening at the joints between segments and rings becomes unnecessary.
- Because metal fixtures are not exposed on the surface and water cut-off quality is excellent, the segmental lining itself has a smooth inside surface and a secondary lining can be omitted.
- Because a state of compression can be maintained across the whole concrete cross section by introducing prestress, structural stability and water cut-off quality can be secured even in a tunnel subjected to high internal water pressure.

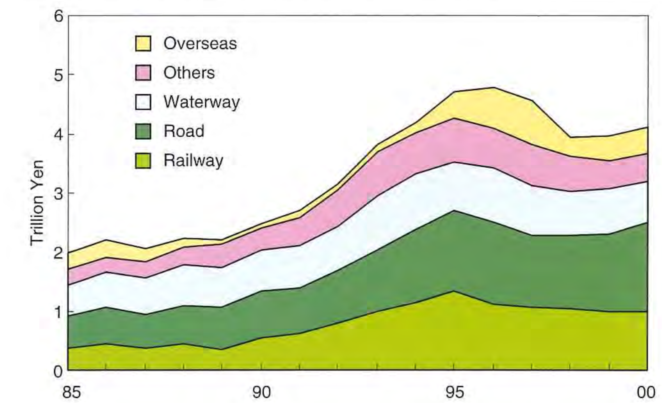
(The Association of Prestressed Precast Concrete Segmental Lining)



General Aspects of Tunnelling in Japan

Trend of Construction Investment in Tunnels and Underground Space

The total amount of construction investment in tunnels and underground space in Japan has been declining continuously since 1995 as a result of the Government's restraint of public infrastructure construction projects. However, the amount of such domestic investment has recently begun a gradual incline. This is because the amount of investment in road tunnels has grown extensively due to the fact that construction work on the New Tomei Meishin Expressway by the Japan Highway Public Corporation has entered its peak period, more than making up for the decline in the amount of investment in waterway tunnels. The amounts for railway tunnels, overseas tunnel construction and others are generally unchanged. The following chart shows the year by year variation in the total amount of tunnel and underground space construction works, divided according to purpose, under contract by the Japanese construction industry.



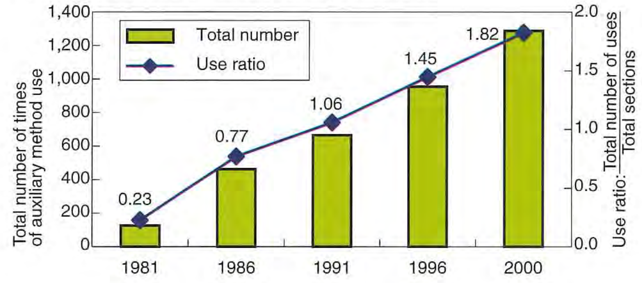
Rapid Increase in Use of Auxiliary Construction Methods in Hard Rock Tunneling

Grout injection and other auxiliary construction methods have been used from the past in tunneling work, but, as shown in the following charts, both the number of times that auxiliary methods are used and their use ratio have continued to increase rapidly over the past 20 years. The principal reasons for this continuing rapid increase in the use of auxiliary methods include the fact that new construction, such as second phase construction, near existing tunnels is increasing, the fact that consideration for the environment surrounding a tunnel is becoming more important, and the fact that design standards for roads and railways have been raised, making it difficult to avoid locations where geological conditions are not good. The increase in the use of forepoling is the most conspicuous, the use of forepoling accounting for approximately one-half of the total number of times an auxiliary method was used in each year since 1996.

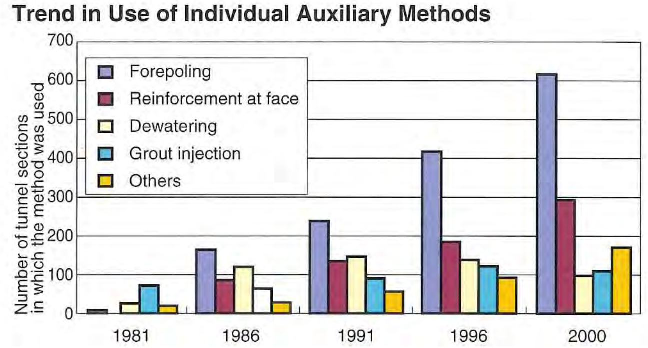
Use of Deep Underground Space

The Special Measures Act for Public Use of Deep Underground Space was approved by the Diet in May 2000 and was put into force on April 1, 2001. This law provides that

Trend in Total Use of Auxiliary Methods



Trend in Use of Individual Auxiliary Methods



in the case of projects for the construction of public facilities such as railways, roads, rivers, gas and communications in the three large urban areas of Tokyo, Osaka and Nagoya, the consent of the land owner is not required for the use of deep underground space below a depth prescribed by government ordinance (generally deep underground space below a depth of 40m from the surface). JTA has been advancing technical studies concerning the use of deep underground space and, following approval of the law, held a meeting to report the results of these studies in November 2000.

Follow-up on Tunnel Lining Fall Accidents

The Ministry of Construction, in February 2000, published the final report of the investigation committee that was formed in response to the tunnel lining fall accidents that occurred on the Sanyo Shinkansen Line in 1999. This report states the inferred causes of these fall accidents and presents proposals concerning tunnel maintenance based on these inferred causes. JTA too, in response to these accidents, has prepared a manual on the construction of concrete tunnel linings.

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2-2-2, Yoyogi, Shibuya-ku, Tokyo 151-8578 TEL:3-5334-1288, FAX:3-5334-1289, http://www.jreast.co.jp

Electric Power Development Co., Ltd.
6-15-1, Ginza, Chuo-ku, Tokyo 104-0061
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Japan Highway Public Corporation
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Japan Highway Public Corporation, Tokyo Construction Bureau
Sumitomo fudosan Tamachi Bldg., 3-39-9, Shiba, Minato-ku, Tokyo 105-0014
TEL:3-5418-2001, FAX:3-5418-2060

Japan Highway Public Corporation, Kyushu Branch
1-4-2, Tengin, Chuo-ku, Fukuoka 810-0001
TEL:92-762-1111, FAX:92-717-1779

Metropolitan Expressway Public Corporation
1-4-1, Kasumigaseki, Chiyoda-ku, Tokyo 100-8930
TEL:3-3502-7311, FAX:3-3503-1806, http://www.mex.go.jp

Teito Rapid Transit Authority
3-19-6, Higashiueno, Taito-ku, Tokyo 110-0015 TEL:3-3837-7132, FAX:3-3837-7208, E-mail:K.NAGOYA@tokyometro.go.jp, http://www. tokyometro.go.jp/

The Kansai Electric Power Co., Inc.
3-22, Nakanoshima, 3-chome, Kita-ku, Osaka 530-8270
TEL:6-6441-8821, FAX:6-6446-6464, http://www.kepco.co.jp/index.htm

Tokyo Electric Power Co., Inc.
1-1-3, Uchisaiwai-cho, Chiyoda-ku, Tokyo 100-0011
TEL:3-4216-1111, FAX:3-4216-4369, http://www.tepco.co.jp

Trans-Tokyo Bay Highway Corporation
Sumitomofudosan Shinagawa Bldg., 4-10-27 Higashishinagawa, Shinagawa-ku, Tokyo 140-0002
TEL:3-5782-7811, FAX:3-5782-7855

SOCIETIES AND ASSOCIATIONS

Express Highway Research Foundation of Japan
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Japan Civil Engineering Contractors' Association, Inc.
6F, Tokyo, Kensetsu Kaikan Bldg., 2-5-1, Hatchobori, Chuo-ku, Tokyo104-0032
TEL:3-3552-3201, FAX:3-3552-3206, E-mail:dokokyo@mx1.alpha-web.ne.jp, http://www.dokokyo.or.jp

Japan Construction Mechanization Association
Kikai Sinko Bldg., 3-5-8, Shibakoen, Minato-ku, Tokyo 105-0011
TEL:3-3433-1501, FAX:3-3432-0289, http://www.jcmanet.or.jp/

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TEL:3-3297-7008, FAX:3-3551-4005, http://www.daiho.co.jp

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2-35, Ichigaya-tamachi, Shinjuku-ku, Tokyo 162-8410
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2-2-11, Minamisenba, Chuo-ku, Osaka 542-0081 TEL:6-6264-3743, FAX:6-6264-3704, E-mail:yo-matsumoto@daisue.co.jp, http://www.daisue.co.jp/

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Fudo Construction Co., Ltd.
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HONMA Corporation
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