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Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2008

JAPAN TUNNELLING ASSOCIATION

CONTENTS

PREFACE

I feel really privileged to be given this opportunity to address tunnel engineers throughout the world on the occasion of the publishing of the 2008 edition of Tunnelling Activities in Japan, Japan Tunnelling Association (JTA)'s biannual publication. Despite the fact that in recent years tunnel construction projects in Japan are on the downturn, our country remains an outstanding global leader in terms of tunnel construction volume, with more than 14 million m^3 excavated annually. Increase in tunnel length and expansion of tunnel cross section are two specific features in mountain tunnels of recent tunnel projects in Japan. The advancement in tunneling technologies in recent years has made it possible to construct economically long tunnels and large section tunnels in the complex and wide-ranging ground conditions in Japan. As a result, it has become possible to choose the shortest routes and higher standards in railway and road projects. In construction of urban tunnels, on the other hand, there are many cases in which construction work is implemented in the proximity of existing structures in areas where there is a convergence of underground structures such as subways, utility lines, etc. In addition, urban tunnels must be constructed to meet strict demands for reducing the impact on the surrounding environment. These factors have fueled the progress in the development of design and construction methods and shield machines that can fulfill the specific requirements for construction of urban tunnels. Based on such recent specific examples, this booklet presents a selection of some typical examples representative of the numerous tunnel projects and technological developments in Japan. I will be pleased if these articles prove useful for tunnel engineers around the world.

Hiroshi KOMORI
President
Japan Tunnelling Association

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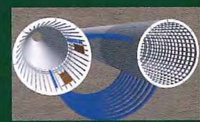
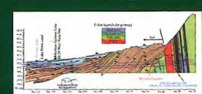
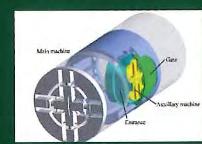
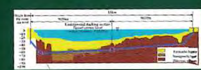
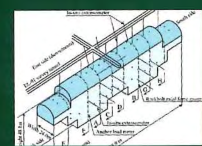










Development and Practical Application of the New Tunneling Technique (SENS) - Sanbongihara Tunnel, Tohoku Shinkansen -

Shoei SAITO
Director, Towada Railway Construction Office,
Tohoku Shinkansen Construction Bureau, Japan Railway Construction, Transport and Technology Agency

Introduction

The Sanbongihara tunnel is a tunnel 4,280 m long, accommodating a double track of Shinkansen superexpress railway, located between Hachinohe and Shin-Aomori under construction. The geology of the site is alternate strata of sandy soil and cohesive soil. The overburden is 23 m on the average, with the groundwater lever above the tunnel crown.

The excavation started by the mountain tunneling method (NATM) in August 2001 from Shin-Aomori side. The geology was more complicated than expected. It was impossible to sufficiently lower the groundwater level or to ensure stability of the face, frequently resulting in collapse at the face.

In the circumstances, through comprehensive study on safety, cost efficiency, work management and construction schedule, a new tunneling method with shield machine was adopted.

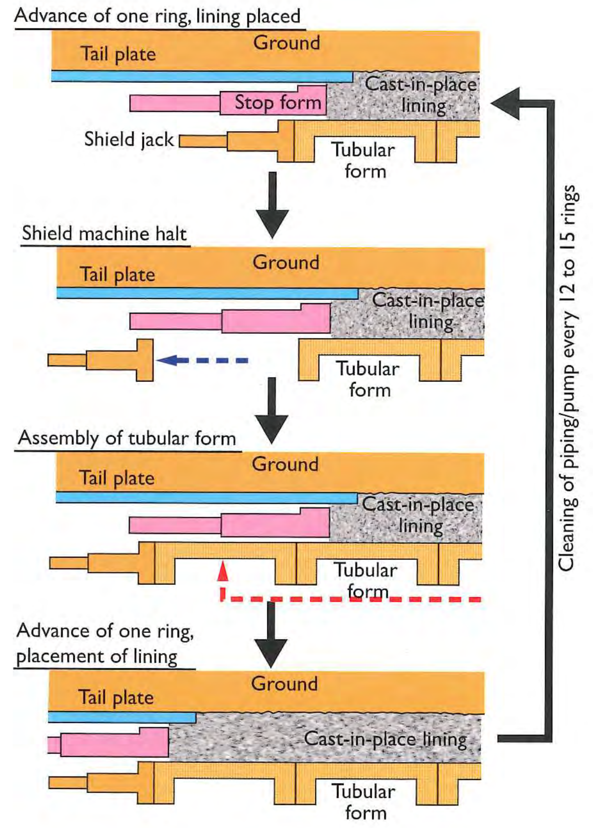
The new tunneling method "SENS"

The new method performs excavation with a shield machine while maintaining face stability. The tunnel support is cast-in-place concrete (primary lining) instead of segments. The concrete is continuously placed along with shield advance, into the tubular form assembled at the rear side of the shield machine. The technique "SENS" combines the merits of shield tunneling and NATM.

Construction records

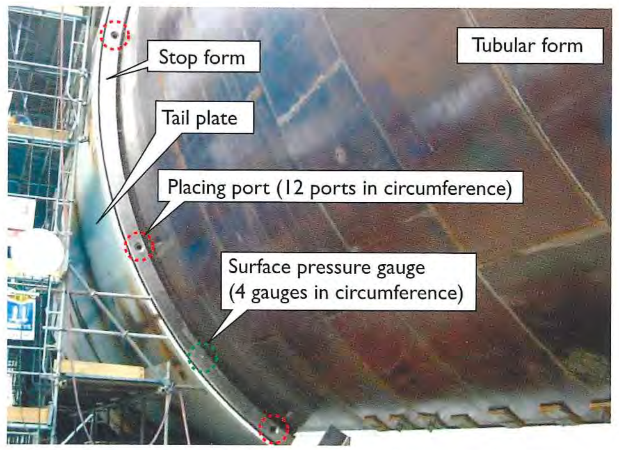
The construction by means of "SENS" commenced in July 2004 from the Hachinohe side opposite to the initial start side. In November 2006, after 28 months or so, a distance of approximately 3,000 m to the point where construction by the mountain tunneling method had been suspended, was driven without any accidents. During the excavation, safety was secured without any face collapse, with monthly average advance of 110 m, that is, about 2.5 times that in the sector by the mountain tunneling method of the same project. The recorded monthly maximum advance was 173 m. In addition, the construction cost was similar to the initial tunneling by the mountain tunneling method.

At present, no well established tunneling technique is available, which is suited to ground characteristics classified as boundary between ground appropriate for the mountain tunneling method (NATM) and the shield tunneling. We expect that, on the basis of the construction results of this project, the technique briefly presented here would find wider application in ground of characteristics similar to those found in this project.



SENS work cycle

Starting of the SENS machine



Lining placement

Development of the Rapid Construction Technique for Tunneling in Soft Rock Ground - Mineyama Tunnel, Hokuriku Shinkansen -

Kenichi TANAKA
Director of 4th Construction Division
Hokuriku Shinkansen Construction Bureau
Japan Railway Construction, Transport Technology Agency

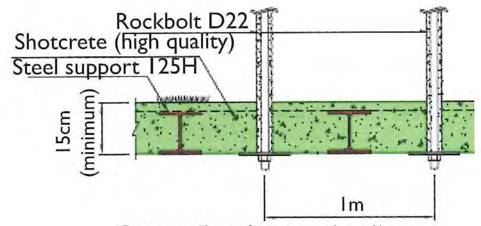
Background and effects of the development of the rapid construction technique

The cost of construction by the NATM has diminished because of improvement of the tunneling method and other factors. However, no significant change has been made in reduction of the work period that has important impacts on the economic effects. Under these circumstances, a rapid construction method was developed for mountain tunneling projects in soft ground.

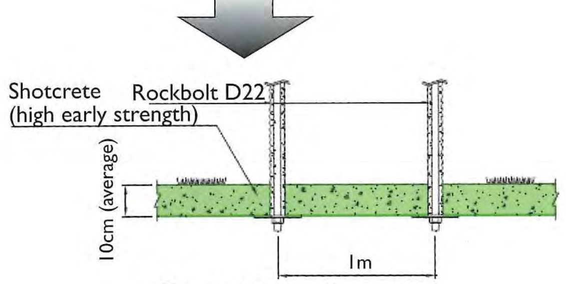
Techniques developed for rapid construction

High early strength shotcrete: It takes three hours for conventional shotcrete to exhibit expected strength. The newly developed shotcrete develops strength of 3N/mm^2 or more in 10 minutes, serving as support immediately after spraying.

New support pattern: Since the high early strength shotcrete exhibits sufficient strength just after spraying, its support capability improves safety in the vicinity of the face. In addition, this shotcrete has high long-term strength, making it possible to work with smaller designed spraying thickness. Moreover, cycle time was shortened because of omission of conventional steel supports (H125) and thinner shotcrete layer requiring less spraying quantity, and reduced excavation quantity.



Conventional support pattern



New support pattern

Large roadheader (350 kW): The cutting capacity and range was designed larger than the maximum size of existing roadheaders. Moreover, the machine width was made more compact to facilitate work in the tunnel.

Excavation automatic control system: High precision excavation based on design tunnel section data inputted, with less overbreak, producing more smooth cut surface. As a result, stress concentration due to surface irregularities is avoided, improving stability of the cut surface.

Large roadheader (350 kW)

Simultaneous excavation and loading: The large roadheader was made compact by reducing the machine width and the heading was divided into right and left portions. Due to this design, excavation and loading can be done simultaneously, thereby shortening the cycle time.

Air curtain ventilation system: In order to control much dust produced during rapid construction, a system was invented, which has special wind tubes mounted at the end of the air feed pipe to form air curtain. The suction port of the dust collector can be positioned very close to the face.

Air curtain ventilation system

Construction results

Of the total length of 7,090 m of the Mineyama tunnel, the sector of 2,430 m was worked by the rapid construction method. The monthly advance was 170 m on the average, with the maximum advance of 304 m in March 2003. Compared with the conventional tunneling method used in soft ground, the cycle time was reduced about 60%, construction period 65% and construction cost 10%.

Tunneling just under the Final Disposal Site of Industrial Wastes - Kozuka Tunnel, Kyushu Shinkansen -

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Kyushu Shinkansen Construction Bureau,
Japan Railway Construction, Transport and Technology Agency

Overview of the tunnel

The Kozuka Tunnel (1,370 m long) on Kyushu Shinkansen railway was constructed by the NATM with short bench cut by the mechanical excavation.

Just above near the midpoint of this tunnel, there is a controlled final disposal (landfill) site for industrial wastes. The tunnel passes just under the disposal site ,at a depth 4 m from its bottom, where landfill is about 40 m thick. There existed a section about 60 m in extremely difficult construction conditions, with the ground to be excavated is the weak boundary stratum. It was therefore essential to prevent tunnel driving from exerting adverse impact on the spill prevention sheet at the bottom of the disposal site.

Study on various measures

In the special section mentioned above, in order to minimize impacts on the disposal site, such as settlement, the pipe roof (812.8 mm in diameter, 66.0 m long, with 13 pipes) and the NATM side heading method were used.

The pressurized slurry jacking was selected for placing the pipe roof, because it satisfies the following requirements; 1) capability of excavating hard boulders (approx. 1.0 to 2.0 m in diameter), 2) not to cause loosening and collapse of pipe-roof-driven surface, and 3) to ensure placement accuracy of 1/500 of the advance distance.

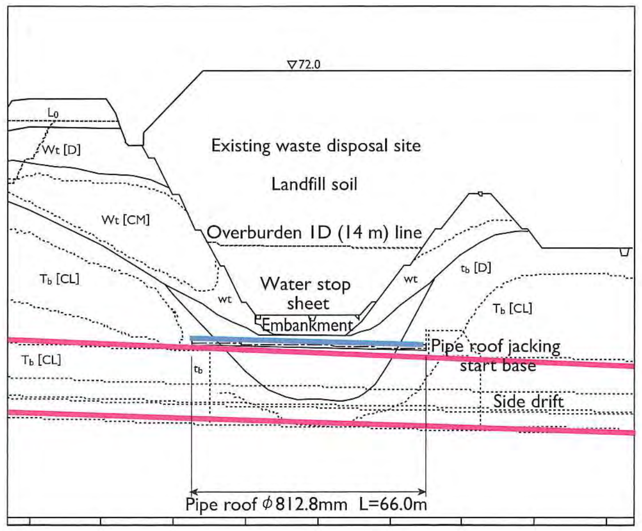
For preventing soil from flowing into the cavity inside the steel pipes, caused by corrosion of the steel pipe roof in the future, the steel pipes were filled with air milk.

Construction

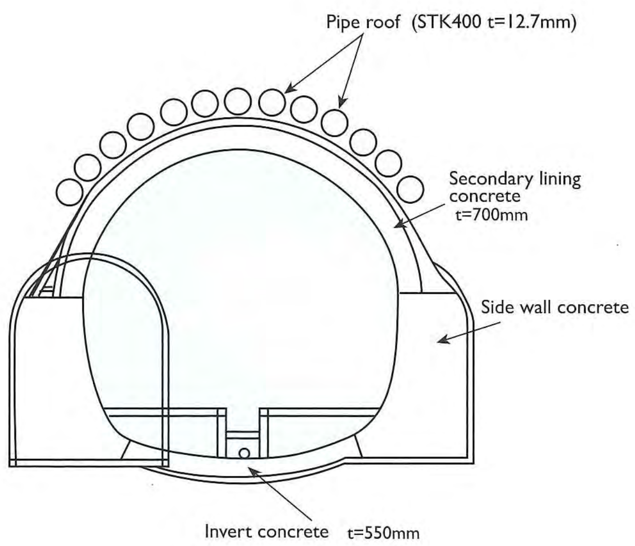
Since the site geology was weak boundary stratum (RQD=0 to 30%), the pipe roof was placed while controlling, ground loosening and displacement, and flexure of hole due to boulders. Consequently, construction accuracy as high as 1/2200 was achieved, far better than the reference accuracy of 1/500.

To curb settlement during NATM excavation in the section where the pipe roof was placed, H250 wing-ribbed steel supports were installed to provide wider support area, and the gap between the pipe roof and steel support was filled with ultra-rapid hardening mortar (σ 3h > 6N/mm^2).

No contaminants were detected by the survey on quality of water inflow in the tunnel, which was conducted after completion of excavation just below the disposal site. This proves that tunneling was completed without exerting adverse impact on the spill prevention sheet at the bottom of the disposal site.



Longitudinal section of the Kozuka Tunnel



Schematic of the countermeasures


Pipe roof

Non-open Cut Construction of a Pumping Room for Water Drainage of the Tunnel - Tokyo Metro Fukutoshin Line -

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Renovation and Construction Department, Railway Headquarters
Tokyo Metro Co., Ltd.

Overview of the construction

The Tokyo Metro Fukutoshin line extending 20.2 km was opened for service in June 2008. Of this length, new construction 8.9 km long needed about six years.

Seven new stations were built. Five of these stations located at relatively shallow levels were constructed by cut and cover, and the two deep stations by shield tunneling.

Overview of the shield tunneling between stations

Shield tunneling was adopted for the sections between stations so road traffic would not be affected. The main features are use of a twin single truck shield tunnel, widened segments, newly developed segment joints, thereby contributing to cost reduction. In addition, a multi-circular shield with smaller section area was used to limit environmental impact by reducing muck discharge.

Overview of construction of a pumping room for evacuating water from the tunnel

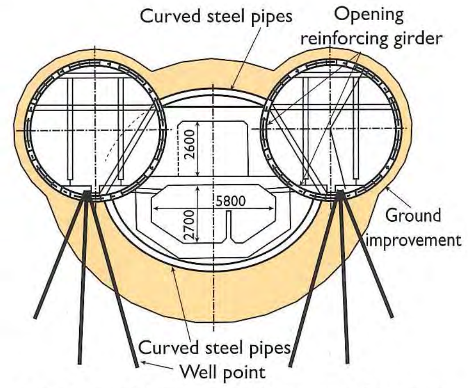
The deepest point (overburden of about 33 m) of the tunnel longitudinal alignment is near the midway of the Takada shield tunnel on the Fukutoshin line. It was therefore necessary to build an intermediate pumping room (total height 7.05 m, cavern 5.8 m wide, 9.4 m long, with two layer structure) for tunnel water evacuation.

Prior to non-open cut construction method of the pumping room, the following issues were identified, consideration being given to the geological conditions (cohesive soil, sandy soil) and construction conditions.

- Occurrence of bottom heaving, boiling etc. due to highly pressurized groundwater (0.32 MPa)
- Poorer work efficiency in the narrow excavation tunnel (delay of work)
- Requirement for ensuring a high degree of safety for vital infrastructure near the pumping room

The following are solutions for the above issues.

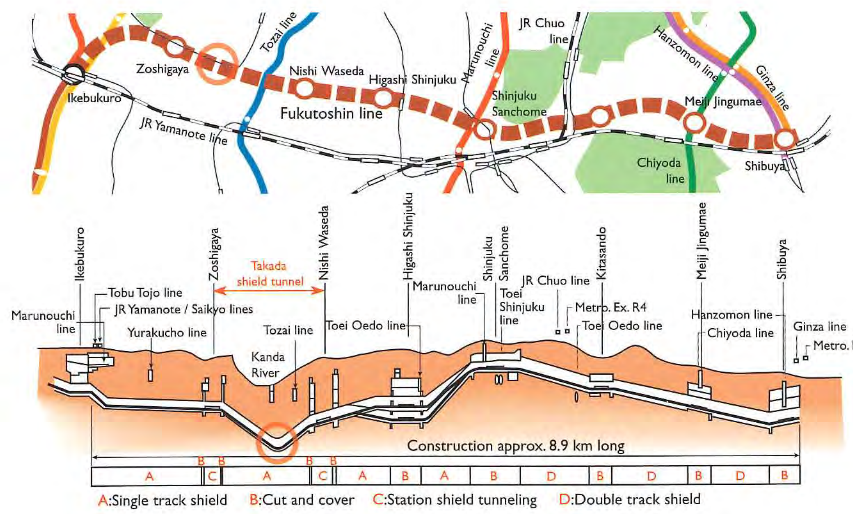
- Ground improvement around the entire circumference of segment back and well point for lowering groundwater from the shield tunnel
- Curved steel pipe support driven from the tunnel to the upper and lower zones of the pumping room (PSS-Arch method)
- Forepoling from the tunnel to both ends of the pumping room
- Installation of reinforcement in the tunnel to prevent the segments from deforming



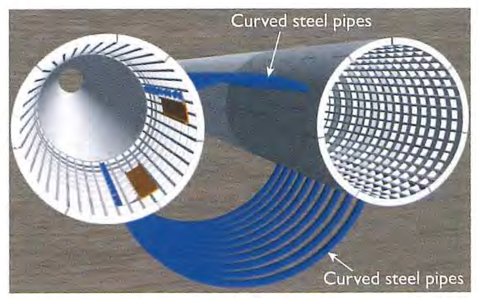
Structure of the intermediate pumping room

Implementation of the PSS-Arch method

With the PSS-Arch method, ground is excavated inside the curved steel pipe supports placed in advance by the use of a curved boring machine. It limits displacements of ground ahead of the face and furnishes safety against face collapse. In this project, ten steel pipes of 5.5 m in curvature radius were driven respectively into the upper zone first, then the lower zone, by means of pipe jacking machine of 80 kN in jacking force from the shield tunnel.



Tokyo Metro Fukutoshin line



Schematic view of the PSS-Arch method

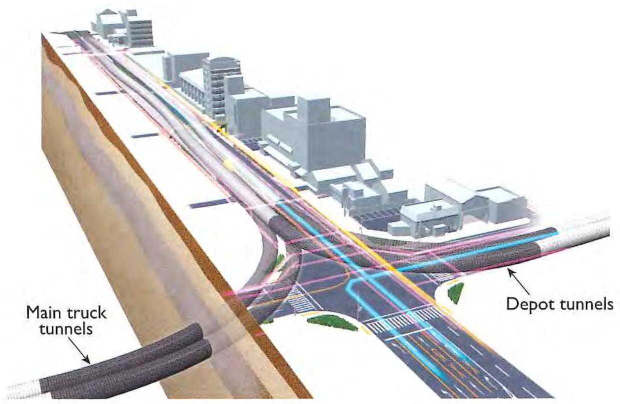
Subway Tunnels with Quadruple Tube and Sharp Curve Sections

Hiroshi YOSHIDA, Chief staff of Engineering Division,
Railway Engineering Headquarters,
Osaka Municipal Transportation

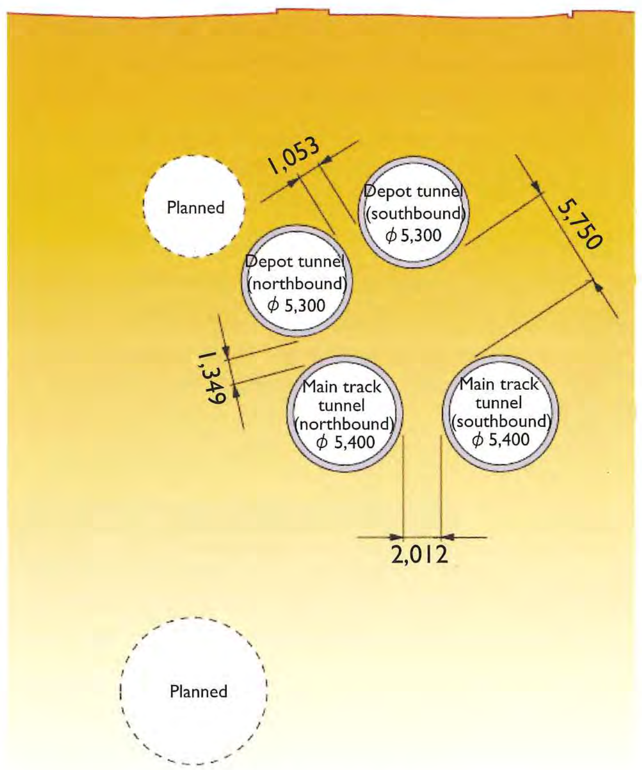
Overview of the project and construction characteristics

The subway No.8 line extends 11.9 km, linking south and north in the eastern district of Osaka city, connecting with the existing railway line between this district and central Osaka.

This shield tunneling project is characterized by an alignment with quadruple tube tunnel section and sharp curve section, these sections being continuous.



Schematic view of the Osaka subway No.8 line



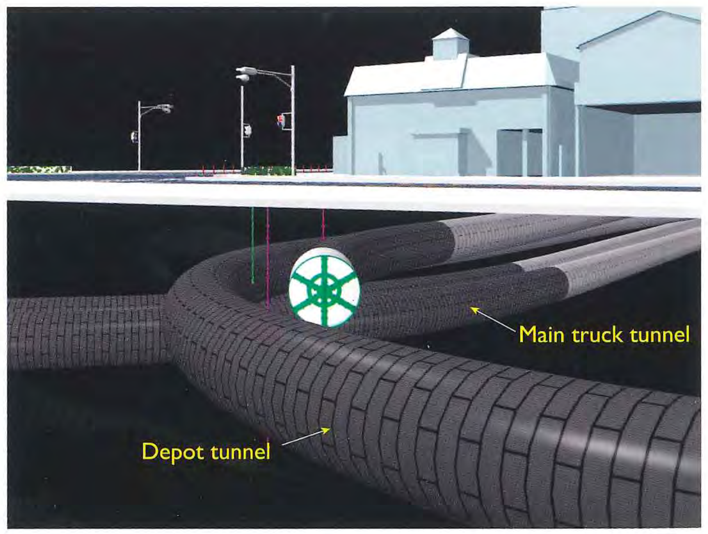
Quadruple tube section

Challenges of the project and countermeasures

The main challenges of the project were prevention of adverse changes of ground, minimizing impact upon existing structures including impact on the tunnel previously constructed, and maintaining steady progress of continuous excavation of the quadruple tube tunnel section and sharp curve section. The geology of the site is a gravel layer prone to collapse and a surface layer of weak cohesive soil. Since the quadruple tube tunnel and sharp curve sections were planned in such difficult geology, there was fear that adverse change in the ground would not merely be limited to accumulation of changes in each tunnel, but change would increase and expand further. Measures taken for these difficulties included ground measurement in the quadruple tube tunnel and sharp curve sections, grouting of air-entrained mortar, appropriate slurry mixing plan in gravel layer, etc.

Measurement results in the section of multiple-tube tunnel and sharp curves

Various experiments and studies mentioned above were conducted and their results were effectively utilized in construction. Tunneling control reference values well suited to the ground of this project were set on the basis of analysis of values recorded during the previous tunnel. Consequently, maximum settlements were limited to 3.8 and 5.8 mm in the quadruple tube section and sharp curve section, respectively. These settlements were significantly lower than the control reference value for national highways of 15 mm.



Sharp curve section

Countermeasures against Water Leaks in a Shield Tunnel Using Lightweight Panels - Improvement Project of the Tokyo Tunnel on the JR Yokosuka Line -

Kenji KOIKE, Assistant Chief,
Tokyo Branch Office,
East Japan Railway Company

Overview of the project

The Tokyo Tunnel is a twin single-track shield tunnel between Tokyo and Shinagawa on the Yokosuka railway line, 12.4 km long, opened in October 1976. At the time of construction, the groundwater level was lower than the tunnel (about 30 m underground). However, due to the restriction of groundwater pumping implemented by the Tokyo metropolitan government in 1971, the ground water level suddenly rose, immersing the tunnel below the groundwater level. Consequently, much water leaked in the section not provided with the secondary lining, and various damages occurred in the tunnel, such as corrosion of steel. The project presented here is to place the secondary lining about 110 mm thick inside the shield tunnel section mentioned above as a permanent measure against water leaks.

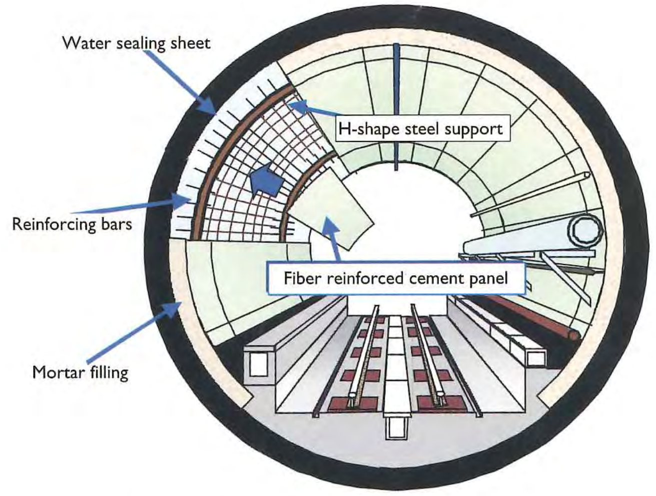
At present work extending about 2,750 m is complete; the remaining section is about 1,500 m.

Work sequence

Now let us look at the sequence of the practice using fiber reinforced cement panels in the Tokyo Tunnel improvement project. For placing the secondary lining that extends to the invert, the high voltage and signal cable troughs are displaced, and the side paths are removed. Then, water sealing sheets are applied over the tunnel segments; and after supports (H-100) are mounted, reinforcing bars already assembled in the form of a lattice in the factory are mounted on the supports. Next the lowest stage of fiber reinforced cement panels that will serve as embedded forms are installed, and then the side paths are restored.

Fiber reinforced cement panels are installed in order until the upper stages. After the panels have been installed, temporary beams for preventing the panels from deflecting are put in place, and backfill mortar is placed. Finally the temporary beams are removed, and the secondary lining placement is complete.

These jobs can be carried out solely during nighttime when there is no train service, generally, from 1:00 to 3:30 am. The work must be done under these rigid conditions.



Schematic of the practice using fiber reinforced cement panels

Before placement of the secondary lining

After placement of the secondary lining

Widening and Reconstruction of a Road just beneath Six Commercial Railway Tracks

Toru KAWASAKI
Vice-Manager,
Tokyo Construction Office,
East Japan Railway Company

Overview of the project

The purpose of this project is to widen and reconstruction a road, currently in service beneath six commercial railway tracks of the JR Yamanote and Saikyo lines and Seibu line.

The project consists of the following steps: removal of the steel railway bridge (girder length = 7 m) and the concrete abutment, now in service, embankment to make subgrade, and using the HEP & JES method, under the railway tracks, construction of one-layer three-span box culverts of concrete-filled steel tubes (width=28 m, height = 9.2 m, total length = 28.5 m).

The construction site is very narrow, and no work yard is available. It is necessary to proceed with construction while allowing traffic on the existing crossing road. The construction period is long, divided into two phases.

HEP & JES method

The part crossing with the railway has an overburden of rail height minus 1.4 m. Box culverts are built by coupling small-section steel elements by the method called HEP & JES.

The HEP (High Speed Element Pull) method pulls the elements directly connected with the pulling excavator into the ground, using a pulling jack and prestressing steel installed on the arrival side, which pulls the pulling excavator. (Fig. 1) The JES (Jointed Element Structure) is a non-open cut method that constructs a rigid box or circular structure below railway tracks, using steel elements provided with joints that can transmit forces. (Fig. 2) The HEP & JES is a combined method of these two techniques.

Overview of the construction

The existing six-span steel railway bridge is an obstacle for the planned road. This project must be implemented while ensuring the road traffic, which makes it impossible to build the entire box culvert at one time. The project is therefore divided into two phases. The first phase is to construct two spans on the Shinjuku side, where the existing viaduct does not interfere with the planned road. Then the traffic on the existing crossing road will be shifted inside the new box culvert constructed in the first phase. The second phase is to construct one span on the Takadanobaba side that interferes with the existing viaduct.

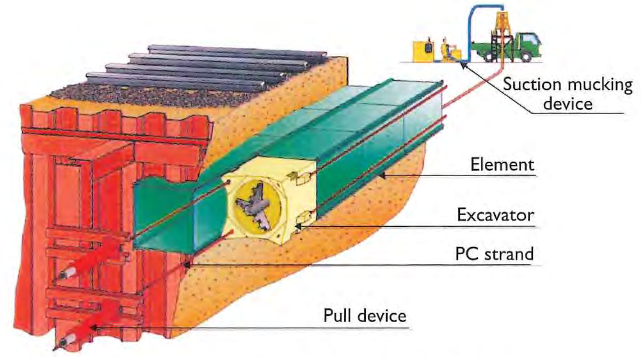


Fig. 1 Schematic of the HEP method

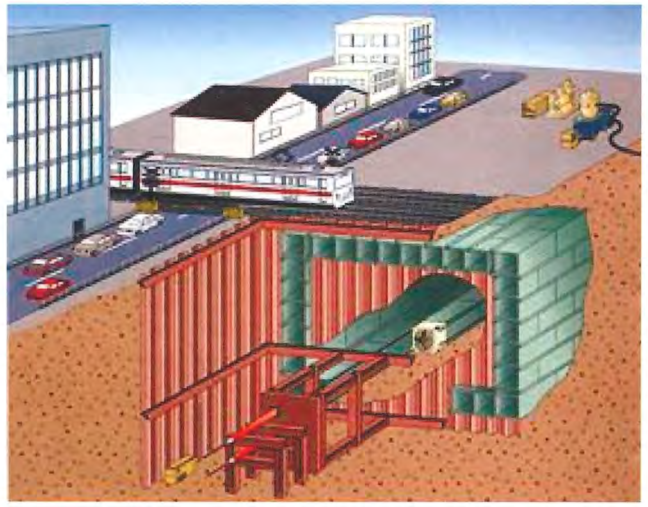


Fig.2 Schematic of the JES method

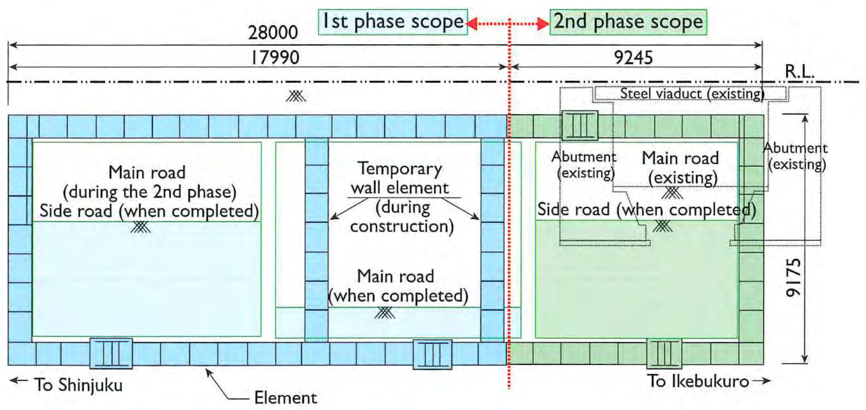


Fig. 3 Cross section of the position crossing the railway

Construction by TBM of a Road Tunnel under the Shinkansen Tunnel

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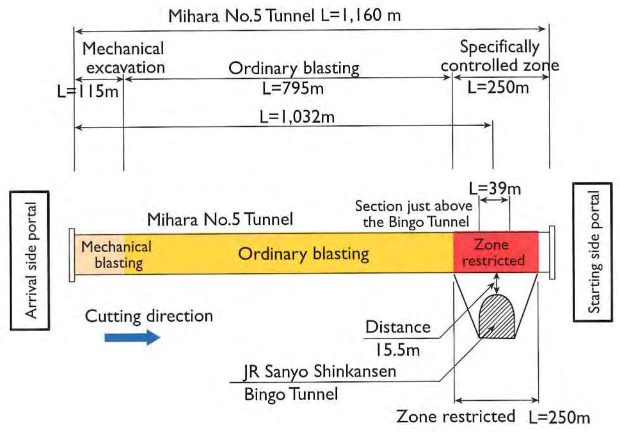
Chugoku Regional Development Bureau,
Ministry of Land, Infrastructure, Transport and Tourism

Introduction

The Mihara No.5 Tunnel (1160 m) on the Mihara bypass (planned 9.9 km long) of national highway No.2 crosses, at around the east portal, very near above the Bingo Tunnel on the JR Sanyo Shinkansen railway. The crossing angle between the tunnels is about 36 degrees and the minimum vertical distance is 15.5 m.



Work conditions of the Mihara No. 5 Tunnel

Work conditions at the closely crossing section

1) The Bingo Tunnel was assessed almost intact. Since the Sanyo Shinkansen is a vital trunk railway linking Kyushu with Honshu, the blasting vibration control criterion was set at 1 cm/sec or less at the tunneling lining, in order to ensure safety.

2) The work time period is limited to three hours in the middle of the night that the Shinkansen line is out of service, 0:30 to 3:30, in the zone of 39 m just above the Bingo Tunnel.

Excavation method in the section the tracks cross closely

In the 250 m zone restricted by the blasting vibration control criterion, as the tunneling face approaches the crossing section, excavation was in the following order:

1) Controlled blasting: The advance per blasting was changed from 1.5 m to 1.0 m. 2) Controlled blasting: use of IC detonators, and 3) Excavation without blasting.

The excavation without blasting uses TBM and rock breaking, because the geology in the zone in question is granite, having an unconfined compressive strength of 150 MPa or more, where cracks are very rare. The work sequence is as follows.

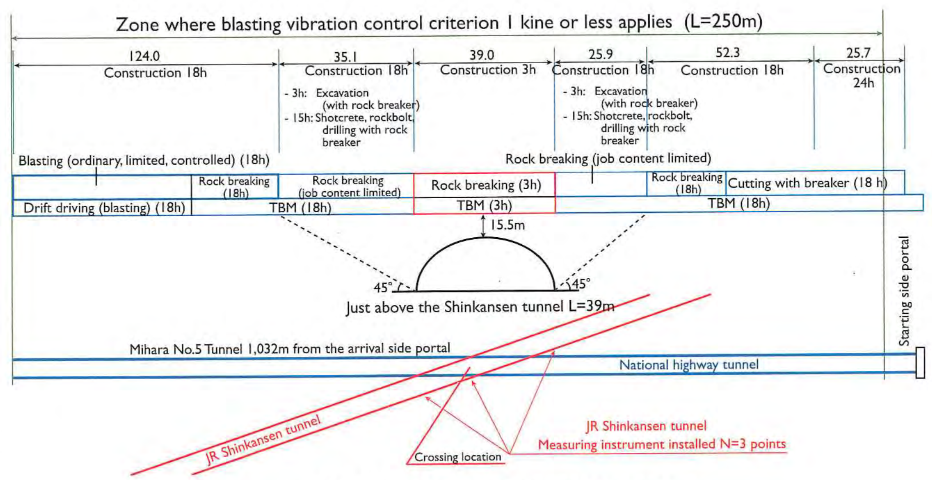
1) The advancing drift is driven by the TBM (4.5 m in diameter, open type, for hard rock), to furnish an access space for a rock breaker.

2) The rock breaker enters the cavity created by the TBM, to make faces midway, thereby breaking rocks from different directions simultaneously (three faces at maximum). This practice offers improved work efficiency.

Work results

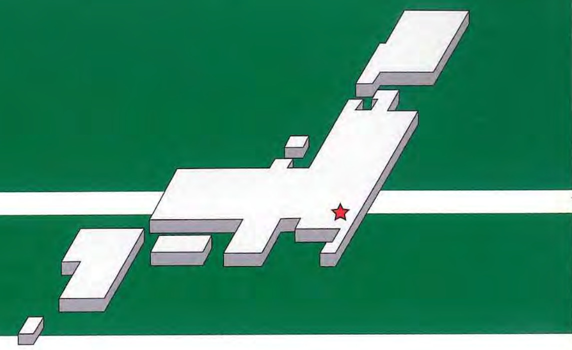
Since the TBM work length is very short, 250 m, measures were taken to minimize the cost, such as mucking by means of a portable belt conveyor instead of a continuous belt conveyor. In addition, jobs were effectively arranged for fully utilizing the limited work time period, and collaboration and coordination with management based on measurements commissioned by the JR company. All these contributed to achieve satisfactory work results including TBM average advance of 4.5 meters per three hours and vibration speed of 0.1 to 0.2 cm/sec immediately above the Bingo Tunnel.

Drilling with rock breaker



Work conditions in the restricted zone

Central Circular Shinjuku Route
- Construction of a Ring Road to Open a New Era of Underground Urban Expressway -



Kenji NAMIKAWA General Manager, First Design Group, Tokyo Construction Bureau, Metropolitan Expressway Co., Ltd.

Naruhiko KAWADA Senior Engineer, Design and Technology Group, Technology Management Office, Metropolitan Expressway Co., Ltd.

Introduction

The Central Circular Route is a road extending 47 km nearest to the core of the Tokyo metropolis, among the three belt lines under construction to alleviate traffic congestion in Tokyo. Almost the entire section about 20 km, western part of the Central Circular Route runs below Tokyo Metropolitan Road. Since the trunk road is located in a densely populated area, there are many underground installations. In addition, rivers and railways intersect with each other at several locations. This project is therefore being implemented under very stringent conditions including protection of the environment along the route and essential existing structures in the vicinity.

Overview of the Central Circular Shinjuku Route

Construction of the Shinjuku route used nine shield machines in the seven work sectors. In the five sectors less than 1 km each, each shield machine made a U-turn in the shaft to drive back and forth within the sector. The portal, cross passage and pumping station were connected with each other by cutting out the segments after completion of tunneling.

Large-section shield tunneling with segment cut-out method

1. Background of the development

For constructing the Central Circular Shinjuku Route, to cope with the stringent conditions mentioned above, the "large-section shield tunneling with segment cut-out method" was developed and applied to the construction. This method is to excavate the main line by shield tunneling, then construct the branching/confluence portion by small scale open cut (or non-open cut).

2. Structural characteristics and design solutions

(1) For this construction method, in the portion between the through-traffic tunnels previously driven, uneven earth pressures apply on the segments when building the ramp tunnel, thereby generating large stresses and deformations. In addition, the tunnel section geometry changes in a complicated manner in the longitudinal direction, resulting in significant change in segment cut position in the longitudinal direction and geometry of the ramp tunnel. Therefore, steel segments that are extremely rigid and easy to fabricate were selected, and a reinforced concrete structure that features higher degree of geometrical freedom was used for the ramp tunnel wall.

(2) Since traffic is crowded at the branching/confluence of road tunnels, it is impossible to support the cut portions of segments with columns. A rational structure should be therefore developed, which transmits stresses from the segments to the ramp tunnel wall. The solution for this project was a rigid structure for the steel-concrete joint to ensure structural stability, and additionally provide sealing against groundwater intrusion.

(3) At the steel-concrete joint, the portions of longitudinal ribs, which were remaining on the main beam of cut-out segments, serve as shear connectors to transmit axial forces to the tunnel walls. For portions where sufficient strength was not ensured merely with shear connectors, studs were welded to the main beams on site. In the reinforced concrete structure, reinforcement was arranged to prevent the main beams from causing horizontal punching shear and splitting. The solution for the joints of this project, using shear connectors, studs and reinforcements, was a novel structure without any record of application. Accordingly, various tests and analyses were made to achieve a rational design.

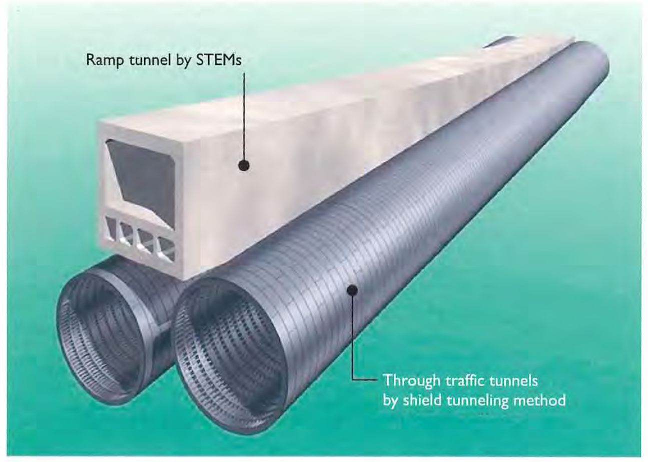
3. Effects of the new technique

The cut-out segment technique was employed at five locations in total, including three ramp tunnels and two branching/confluence of the through tunnel at the Nishi-Shinjuku junction of the Shinjuku Route.

With this technique, tunneling can proceed without dividing the shield tunnel at every branching/confluence point. Consequently, each contractual construction segment was extended, and the project cost was cut about 12 billion yen.

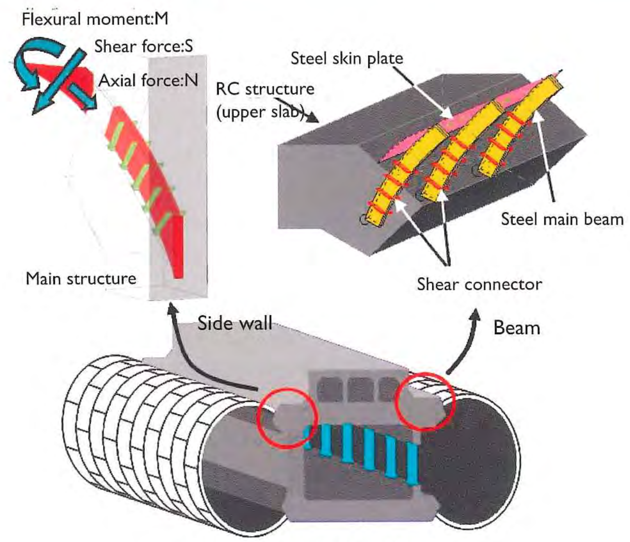
Project and work overview of the Ohashi junction

The Ohashi junction connecting the viaduct structure of the No.3 Metropolitan Expressway with the tunnel of the Central Circular Route was designed in the shape of a loop 400 m in circumference. To pass through the difference in elevation between the viaduct and tunnel, it is necessary to make two rounds on the loop. The tunnel to this loop from the Central Circular Shinjuku Route is a section with twin shield tunnels in the vertical direction 430 m long. Since the tunnel length is short, it was also constructed by turning a single shield machine. Due to a vertical twin tunnel configuration, the shield machine weighing about 2,000 t was put on a bench in the shaft, and lifted with 14 jacks of 400 t to be lowered and rotated.

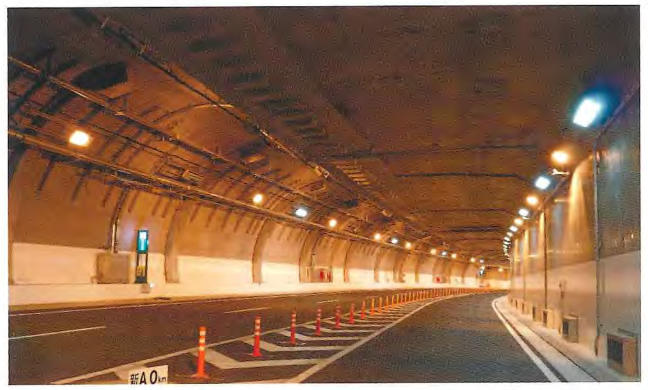


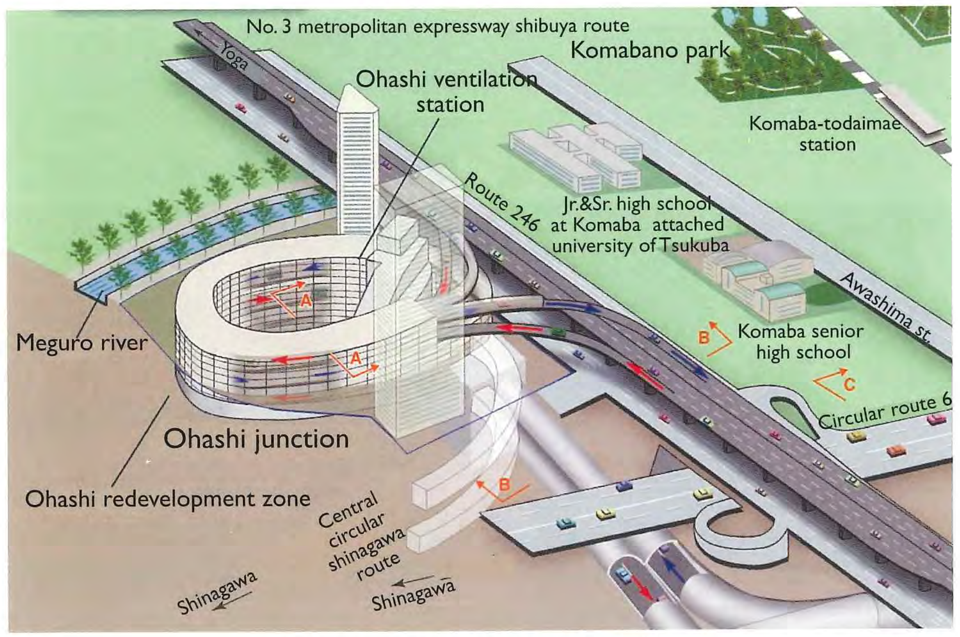
Schematic of branching/confluence

Central Circular Route plan



Detail of cut-out scheme


View of the completed cut-out work



Drawing of completed Ohashi junction

Road Tunnel Construction by Large Section Shield Tunneling in an Urban District - Akita Central Road -

Takashi SUGAWARA
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City Planning Division, Construction and Traffic Department,
Akita Prefecture

Introduction

The Akita Central Road is a Regional high-standard highway constructed in order to alleviate traffic congestion in central Akita. For construction beneath Akita Station, large section slurry shield tunneling 12.2 m in diameter, 1,524 m long was adopted.

Characteristics of the project

1 Main features of the project

1) Construction period shortened by using one-pass segments with smooth inner surface
2) Road shield tunneling without placing the secondary lining
3) Installation of fireproof boards
4) Horizontal movement of the shield machine (movement about 200 m in the culvert)
5) Invert constructed with stabilized soil using muck produced during tunneling

2 Specification of the segment

For achieving rapid assembly and omission of the secondary lining, the one-pass segment joint was selected. waterproofing of the segment joint was designed with a double seal gaskets to improve watertightness of the tunnel.

3 Fire protection

An automobile fire in a tunnel may produce heat exceeding 1000 deg. C, which would fracture concrete, undermining stability of the tunnel structure. Since the Akita Central Road is a road shield tunnel not provided with secondary lining, the segments are directly exposed to high temperatures in a fire. The segment surface is therefore covered with fireproof boards.

4 Horizontal movement of shield

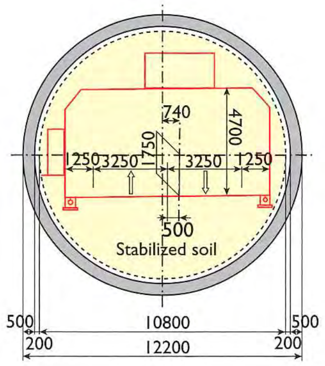
After arriving at the culvert in the moat section already constructed, the shield machine was moved horizontally by the jack, using the configuration of ball bearings to decrease the friction coefficient. This movement system used the function of rolling bodies, i.e., iron balls (90 mm in diameter) placed beneath the shield machine base. The shield machine features an articulated mechanism well suited to work in a sharp curve (R=280 m), and a structure divided into multiple parts in order to satisfy the restriction on land transport (main body divided in 84 parts).

5 Subgrade of the tunnel

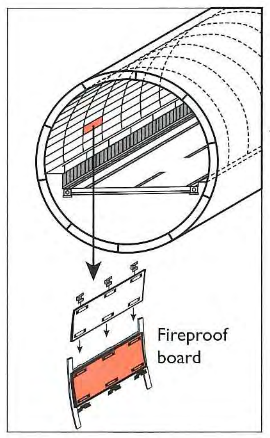
Tunneling by slurry shield produces construction waste, that is, slurry. Excess slurry produced by excavation is stabilized and used for making the subgrade, thereby effectively utilizing resources and reducing the amount of industrial waste produced.

One-pass segment with smooth inner surface

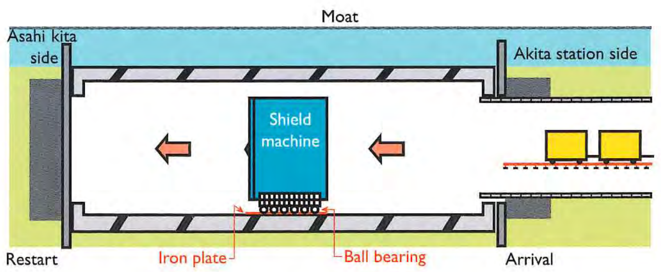
Horizontal movement of the shield machine



Standard section of the shield



Installation of the fireproof board



Schematic of horizontal movement of the shield machine

Construction of a Box-Shaped Road Tunnel beneath a Railway Viaduct

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Vice Manager,
Tokyo Construction Office,
East Japan Railway Company

Overview of the project

The Circular Route No.2, a road in the scope of city planning, crosses a viaduct carrying six commercial railway tracks of the JR Tokaido line, Yamanote line and another line. The crossing section is a box-shaped tunnel. This tunnel is near the foundations of the Tokaido Shinkansen railway, and below them are railway and sewerage trunk channel constructed by shield tunneling. The tunneling project was implemented under these severe restrictions. The JR viaduct was a brick structure with short spans built around 1900. In order to construct the box-shaped tunnels, it was necessary to remove the viaduct in advance without impairing the railway function.

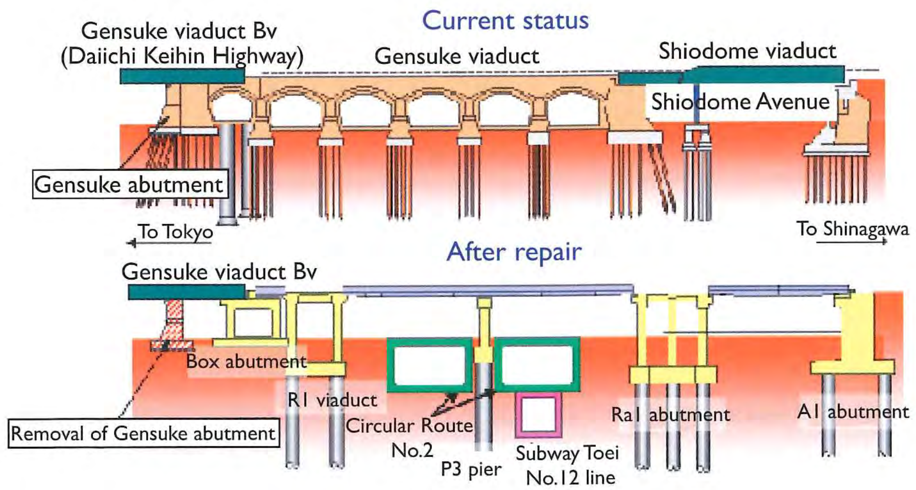
Overview of the construction

The temporary girders were placed during about 3.5 hours in the middle of night when the railway was out of service. The foundation piles of the piers that support the temporary girders were cast in place by the TBH method (1,800 mm in diameter, 21.6 m long x 33 piles). Since these piles were built below the existing viaduct, the work was difficult with a limited overhead clearance.

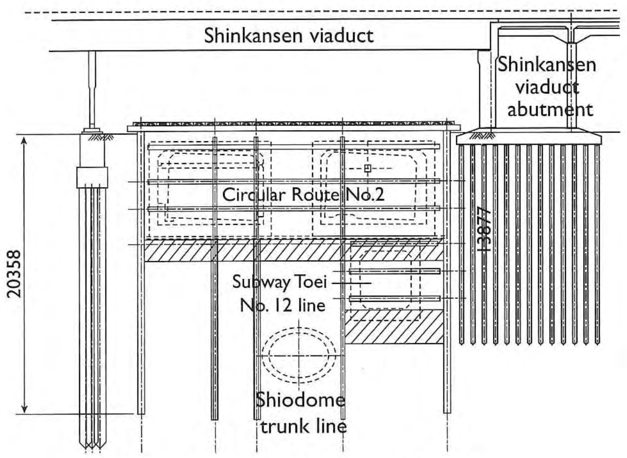
The tracks on the viaduct were supported temporally and the viaduct was removed. The arch of the viaduct was removed using the following steps. The arch was cut with a wire saw into pieces weighing around 70 t each, and the pieces were lowered to the ground and divided into blocks of about 10 t each to be brought out.

Since the subway link line was planned to be constructed beneath the road tunnel, the tunnel excavation depth was set at about 15 m. In the tunnel excavation section, in addition to the JR East Japan railway, the foundation of Tokaido Shinkansen exists in the vicinity. Therefore, an earth retaining wall was constructed to curb alterations due to excavation. Since the shield tunnel on the JR Yokosuka line and sewerage trunk shield tunnel run below the planned tunnel, ground was improved to deal with possible floating up caused by stress release during excavation.

In order to avoid impact on the railway traffic, the viaduct was restored by reinforcing temporary steel girders of about 11 m span to make permanent girders of steel plus concrete structure of 21 m span, which straddles the box-shaped tunnel.



Section of JR Tokaido line



Section of the Shikansen viaduct

View of piling

Excavating Soil and Rock by a Single Shield Machine

- Inariyama Tunnel, Kyoto Route of the Hanshin Expressway No. 8 -

Yukio ADACHI
Assistant Manager,
Kyoto Construction Department,
Hanshin Expressway Company Limited

Summary of the tunneling project

The Inariyama Tunnel on the Kyoto Route of the Hanshin Expressway No.8, a motor highway south of Kyoto city, composed of two lanes in each direction (four lanes in total), is approximately 2.7 km long. The two tunnels, one going to the east and the other to the west, respectively have a length of approximately 2.5 km. A 1.5 km section on the east side was excavated and completed by the NATM method, and the 150 meters on the west side by the open cut method. The project we introduce here is tunneling a length of around 855 m in the center section using the shield machine.

Characteristics of the project

The prominent feature of this project is using only one shield machine of a large external diameter exceeding 10 meters, which excavated not only the geology composed of soil and but also that of solidly consolidated rock containing fractured zones. When designing this shield machine, to meet the above requirements, we considered that the machine in question should be able to change the cutter from the type with cutter bit for soil ground to the type of roller cutter for rockmass. The driving unit and cutting plate also are designed to meet the requirements for boring in both soil ground and rockmass.

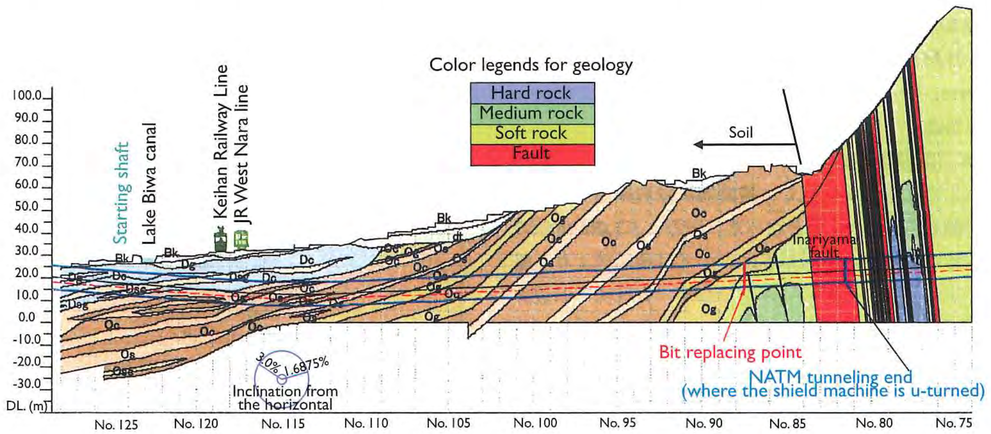
During excavation, at the moment the shield machine arrived at the geological transition zone from soil ground to rockmass, or from rockmass to soil ground, the cutter bit was replaced by cutter inside the machine chamber behind the cutting face; twice in total, one when heading east and the other when heading west.

Composite segments were used, and the process of secondary lining was omitted to reduce the excavation section area and to reduce costs. Fire-resistant material was laid in place of secondary lining (wet shotcreting, 3 cm thick) on the segment surface, and fire-resistant segments (polypropylene fiber-based reinforcement material) were placed in some sections.

In addition, there are other challenges we faced in the course of the project, but the very strict construction management rules we adopted allowed us to complete the excavation project successfully by overcoming various problems such as;

- Starting excavation under a thin earth covering (4.8 m overburden)
- Crossing a section just below the Lake Biwa canal (distance from the channel 4.4 m)
- Cross the area just under the two railway lines, only leaving a small distance (earth covering 1.2 times the tunnel diameter)
- Passing just under an area where residences are close-packed (section length 500 m).

At the first stage, the shield machine advanced to the west. When arriving at a cave excavated by the NATM method to be larger in diameter than the tunnel, the shield machine was turned in the opposite direction, via a ball type heavy carrying device. Then, the machine advanced to the east toward the starting position. This tunnel excavation project was able to be finished without troubles.



Longitudinal section of geological profile

Cutter for soil

Cutter for rockmass

Arrangement of cutter bit

Design and Construction of a Tunnel Crossing Large Landslide

-Akaiwa Tunnel, Dodo Yubari Shintoku Route-

Hideaki NAGAYAMA
Director, Road Construction Division
Asahikawa District Public Works Management Office,
Hokkaido Government Kamikawa Subprefectural Office

Overview of the project

The Akaiwa Tunnel, 2,115 m long with two lanes, is located near the center of Hokkaido,.

Survey of the landslide

Additional survey after commencement of the tunnel excavation revealed that the tunnel route crosses a landslide as deep as 120 m. From further survey and analysis, we learned that the landslide moves very slowly and predicted that it would tend to stop if dewatered. Therefore the tunnel route was not changed, and the decision was made to proceed through the landslide zone.

Solutions adopted

1) Measures for ensuring safety

The groundwater level was substantially lowered by boring to dewater the tunnel. This worked very effectively to curb landslides.

Solutions for safety of the tunnel structure and tunneling progress were highly rigid double supports, and most advanced auxiliary methods including long steel pipe forepiling, long face bolts, and long self-drilling type dewatering.

2) Measures for ensuring functions

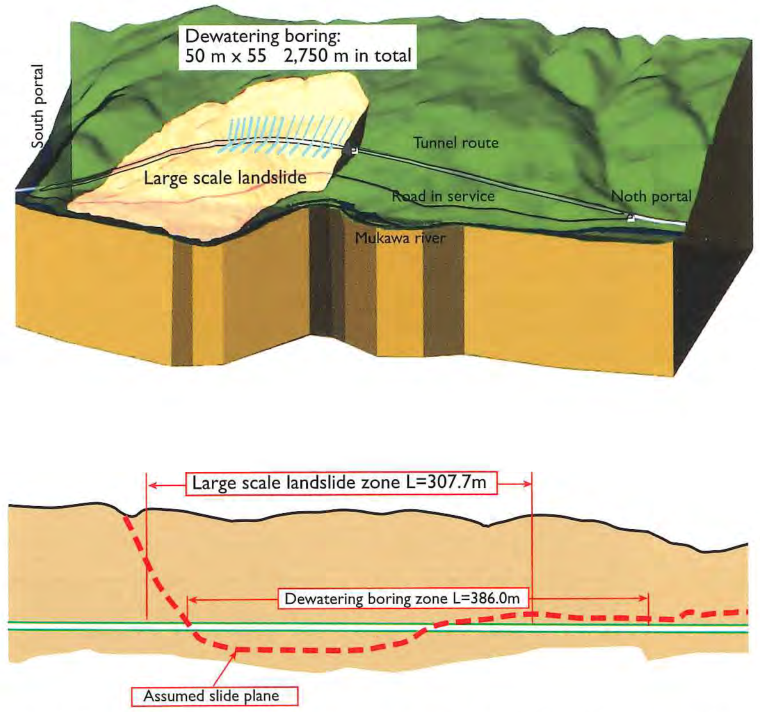
In order that the groundwater level continue to drop from the boring for tunnel dewatering, pipe with bristles were used to gather water, which prevented clogging. In addition, a configuration was invented, which allows cleaning of the water collecting holes, and enables re-drilling.

3) Other functions

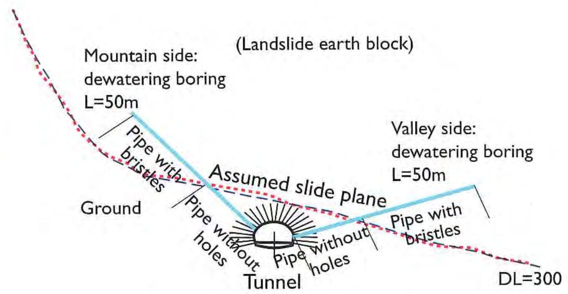
To make the lining concrete capable of resisting landslide loads, fiber reinforced concrete was selected. It has high strength (50 N/mm^2), with dense bar arrangement (main reinforcement D32 at 125 mm intervals). For dispersing landslide loads, one placement cycle of lining concrete was set at 6 m, and flexible lining structure was adopted, which has 5 cm joint material and slip bars at the construction joints.

Management and maintenance during service

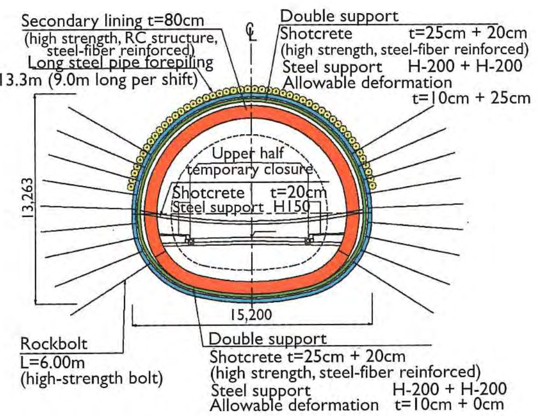
A management and maintenance manual was prepared specifically for the Akaiwa Tunnel. According to the manual and management criteria for traffic control, etc., along with monitoring during service, maintenance is performed to ensure traffic safety and long-term function of the tunnel.



Schematics of the large-scale landslide zone and dewatering boring



Standard dewatering boring



Support pattern example

Construction of a Tunnel in Highly Pressurized Water Zone of Karst -Jiyoshi Tunnel-

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Shikoku Regional Development Bureau,
Ministry of Land. Infrastructure, Transport and Tourism

Overview

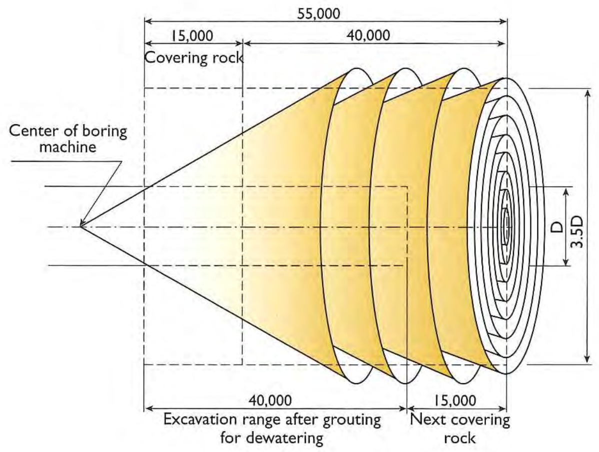
The Jiyoshi Tunnel is a road tunnel 2,990 m long with overburden up to 400 m, passing the Shikoku Karst, one of the three major Karst formations in Japan. The geology is an accretionary zone of the Jurassic period. The zone 700 m from the portal is composed of slate mixed with green rock, the zone of 700 m to 1,220 m is limestone containing a huge volume of groundwater under high pressure, and beyond 1,220 m mixed rock of slate or green rock and limestone.

In the limestone stratum, around 700 m from the portal, sudden water ingress of 20 t per minute occurred. Since then, tunneling continued by utilizing auxiliary methods such as grouting to cope with maximum water ingress pressure of 2.7 MPa. However, weak mixed rock (melange) intercalated by limestone, crushing of the tunnel supports and heaving occurred, twice causing face collapse. In the fault zone, 1180 m from the portal, collapse of the face and crown of 100 m^3 took place at the geological boundary. In each of these cases, excavation of the main tunnel was suspended and the plan was changed to drill a detour drift.

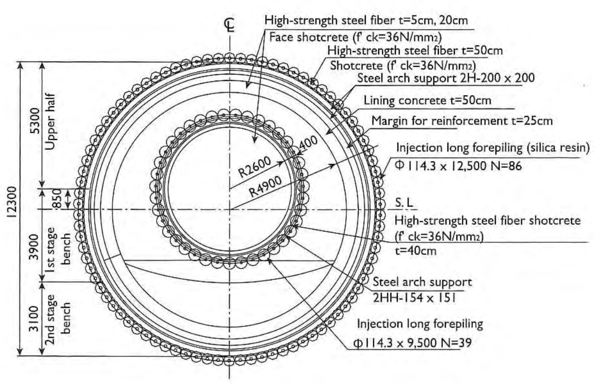
Currently, to advance through this highly pressurized groundwater zone, tunneling is being continued using mainly the following techniques and methods.

1) Advanced long horizontal boring by the double reverse method capable of easily surveying the highly pressurized huge volume water ingress zone, to verify the geology ahead of the face.
2) Grouting combining both conventional sodium silicate based grout having excellent water sealing performance and cement-based grout featuring high strength and durability.
3) Design of rational water seal zone utilizing advanced support effect of the injection long forepiling driven for preventing ground ahead of the face from loosening.
4) Design of circular supports to prevent the tunnel from deforming due to water ingress under high pressures.
5) Full face cutting method with divided central advanced drift to achieve section closure at an extremely early stage.

Heaving in the zone without countermeasures



Overview of grouting for dewatering



Main tunnel section

Construction of the main tunnel

Tunneling through Yubari Mountains - Hobetsu Tunnel, Transverse Hokkaido Expressway -

Masahiro SASAKI
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Chitose Construction Office, Hokkaido Branch,
East Nippon Expressway Company Limited

Overview of the project

The Cross Hokkaido Expressway (between Yubari and Tomamu) is a national road extending 63 km passing through a steep mountain district. On the route, construction of twelve tunnels in total is planned, including three tunnels as long as 4,000 m long respectively.

The geology around the planned route is composed of mudstone and serpentine of the Cretaceous period in the Mesozoic era. Serpentine that appeared during excavation did not include swelling mineral. Squeezing nature is therefore mainly attributable to volume dilatation due to stress release.

Construction status

In the Hobetsu Tunnel, the longest tunnel on the expressway, serpentine was found in a wide range at the center of tunnel route before excavation. It was greatly concerned that the swelling nature of this rock and large overburden (350 m at maximum) would adversely affect tunnel excavation. Therefore, an evacuation drift (cutting sectional area = 19 to 26 m^2) was driven in advance, parallel with the main tunnel (cutting sectional area = 91 to 130 m^2). The data measured during the drift excavation were utilized in design of support structure and construction of the main tunnel. (Fig. 1)

In the zone 3,926 m long already excavated of the evacuation drift, foliated serpentine was found over a total distance of 650m. At this location, because the tunnel was entirely subjected to squeezing, significant heaving of 400 mm, and loosening as much as 3m in the tunnel surrounding occurred. Moreover, due to stresses exceeding the support strength, damage in the invert strut (Photo 1) and cracking in shotcrete took place. As countermeasures against these damages and troubles, fiber reinforced high-strength shotcrete (36 N/mm^2) was placed, successfully curbing further displacements. (Fig. 2)

With measurement data of the evacuation drift driven first, the physical properties of ground were determined by FEM reverse analysis. Then the support structure and auxiliary methods for the main tunnel were studied by FEM analysis. The technique selected through these studies was double support with high-strength shotcrete and high performance steel beam.

In the zone including serpentine that will be encountered in the main tunneling planned, basically using the technique mentioned above, measurement data will be analyzed and evaluated, feeding back the analytical results to construction to proceeding with the tunneling.

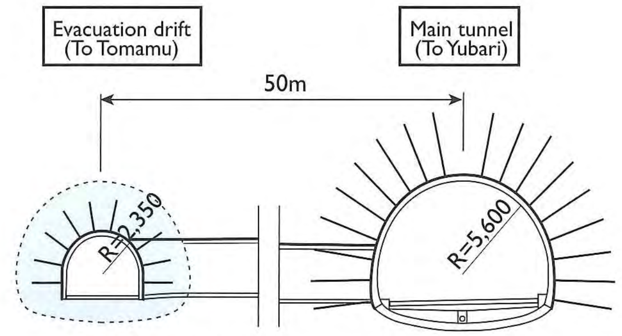


Fig. 1 Tunnel cross section and arrangement

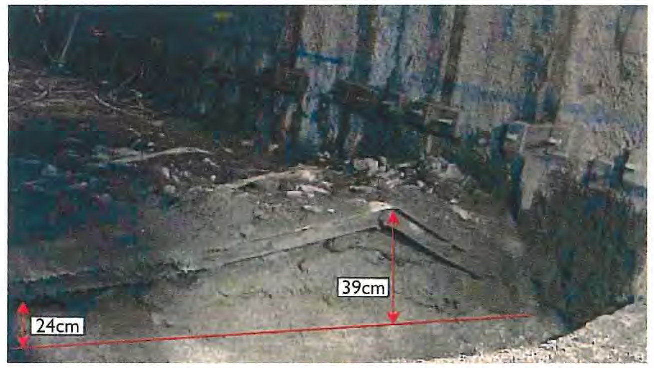


Photo 1 Damage of the invert of the evacuation drift

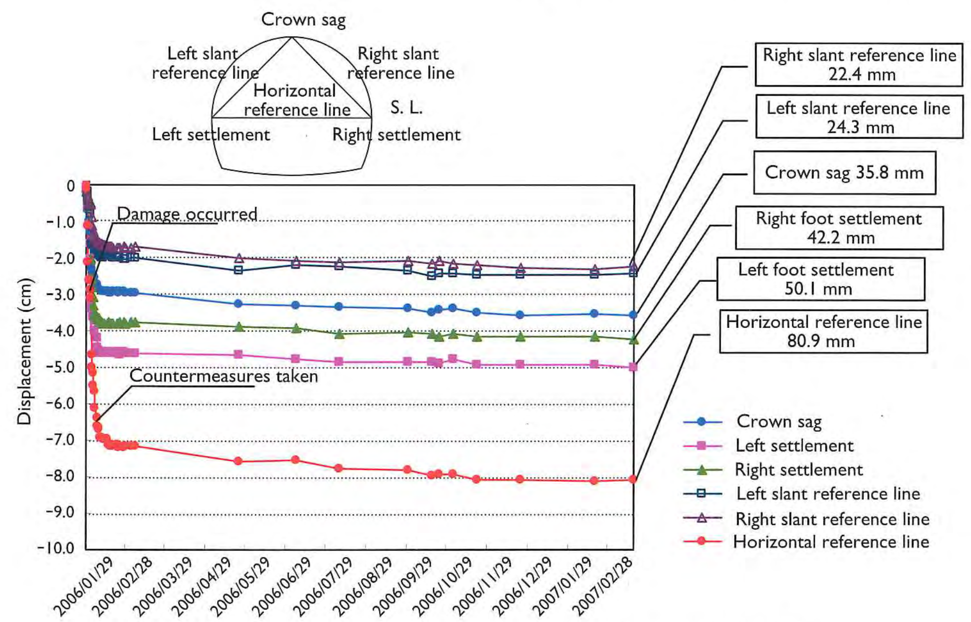


Fig. 2 Displacement measurements in the evacuation drift

Construction by TBM of a Long Tunnel and New Ventilation System -Hida Tunnel, Tokai Hokuriku Expressway-

Mamoru MORIYAMA
Hida Construction Section Manager,
Kiyomi Construction Office, Nagoya Branch,
Central Nippon Expressway Company Limited

Overview of the project

The Hida Tunnel is the second longest road tunnel in Japan, with maximum overburden of 1,040 m, 10.7 km long, composed of a two-lane main tunnel and an evacuation tunnel. Since the vertical alignment is simply inclined 2%, the tunneling is performed in a single direction. Consideration was given to this condition, construction period and geology, and a TBM capable of excavating rapidly was selected both for the main and evacuation tunnels. The TBM excavation diameter of the main tunnel is 12.84 m, one of the largest diameters in the world. This tunnel was open to traffic in July 2008, when the entire length of the Tokai Hokuriku Expressway was put into service. This expressway is expected to play a vital role as a north-south trunk route in Tokai Hokuriku area.

TBM for the evacuation drift broke before reaching the goal

Construction of the evacuation tunnel

Prior to excavating the main tunnel, the evacuation tunnel was driven first for the purpose of confirming the geology and drainage. The results of real time assessment of the ground on the basis of the TBM data were referred to in operation of the TBM. However, adverse phenomena not initially anticipated occurred, including a poor ground zone extending about 1.7 km of thermodynamically altered rhyolite, a zone where water ingress exceeding 70 m^3/minute, one of the largest amounts encountered in tunneling in Japan, and just before breakthrough, the TBM was trapped in a clay layer that had been fluidized by water ingress under high pressure exceeding 6.5 MPa at maximum. Excavation was completed in March 2006 even though the TBM had been stuck in the ground nine times and there had been 20 collapses.

Main tunnel lining with fireproof segments (Front: fireproof segments, Back: ordinary lining)

RC liner section of the main tunnel TBM (before placement of the secondary lining)

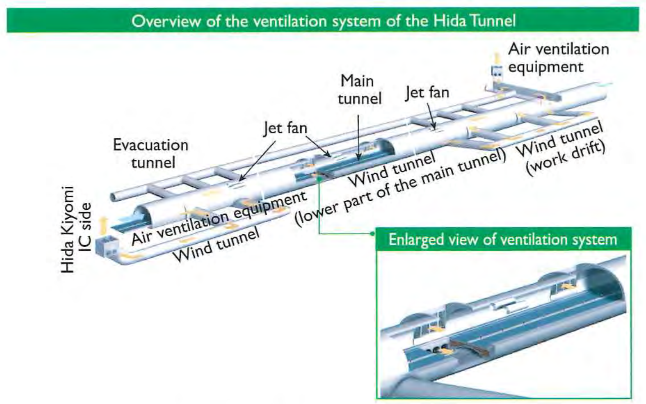
Construction of the main tunnel

On the basis of the work results of the evacuation tunnel, the TBM was provided with functions to cope with poor ground and large-volume and high-pressure water ingress. However, during construction, difficulties were encountered, such as massive highly pressurized water ingress and significant wear of the cutter head disc caused by collapse of the face. For drainage and countermeasures, an additional work drift was constructed in the position opposite to the evacuation drift before resuming driving with the TBM. In the poor ground, excavation was made partially by the NATM. Also in the poor TBM driving zone, RC liners that enable TBM jacking were used in ground of an adverse nature. For the purpose of shortening the construction period and future engineering development, the single shell RC liner structure and multiple shotcrete lining were used in a section. This liner structure intrinsically has fireproof properties.

Ventilation system

The lower half of the TBM section and the additional work drift mentioned above are effectively utilized as air ventilation duct. In addition, through study of the traffic characteristics, with selective exhaution longitudinal ventilation system was used. This is the first attempt in the world. The ventilation system is controlled by the model-based prediction ventilation control (MPVC). This ventilation and control system ensures economic and efficient ventilation.

(Contact: Engineering@c-nexco.co.jp)



Overview of the ventilation system

Excavation of an Ultra Large-section Tunnel in Weak Ground -Kanaya Tunnel, New Tomei Expressway-

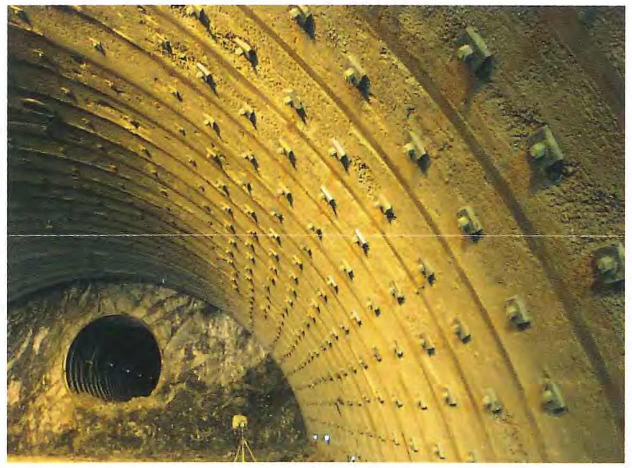
Hiromitsu KISHIMOTO
Construction Section Manager,
Kakegawa Construction Office, Yokohama Branch,
Central Nippon Expressway Company Limited

Overview of the project

The New Tomei Expressway is 350 km long, linking Tokyo and Nagoya. The Kanaya Tunnel, located almost at the center of the expressway, is a twin tunnel with the eastbound lanes 4,527 m long and the westbound lanes 4,667 m long. The geology is divided into two zones, with the boundary at the center of the tunnel, Palaeogene alternate strata of sandstone and shale, and Neogene mudstone. Weak ground with competence factor of 4 or less accounts for 78% of the tunnel total length. Since the excavation sectional area is as large as 190 m^2, tunneling with TBM-bored advance drift was selected to ensure a high degree of safety and work efficiency. This selection furnishes not only safety of the face during enlarging work, but also enables determination of the geology in advance, and advanced ground reinforcement from the drift, as well as use of economic supports.

For zones that were particularly weak (competence factor 2 or less), the measures discussed below were taken.

Driving the cable bolts from the TBM-bored drift



Driving the prestressing steel bar pattern

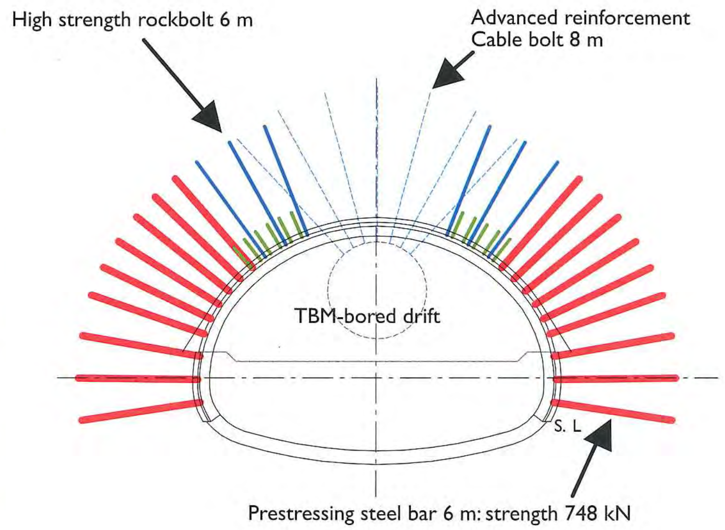
Use of a new technique in TBM drift driving

"Rapid construction" and "ground fastening means" were the primary considerations for the TBM drift driving. Techniques adopted from this standpoint were TBM navigator automatic measurement system, extensible TBM steel liner, and steel liner giving reaction for the TBM shield jack. In addition, reflection tomography for surveying ahead of the face was implemented in the weak ground, enabling effective driving. The maximum monthly advance was 682 m, and even in weak ground, driving advanced 226 m per month.

Special support patterns in the weak ground section for constructing the main tunnel by widening

Supports stronger than conventional materials were used, such as rockbolts (strength 290 kN), shotcrete (36 N/mm^2) and steel supports (yield point 440 kN/mm^2). The standard support patterns are combinations of these components. However, in the weak ground section, the face collapsed and the supports were noticeably damaged. In order to limit initial displacements and improve the support strength, ultra-high strength prestressing steel bars (32 mm in diameter, strength 748 kN), and cable bolts were driven in advance for preventing the crown from falling during excavation for widening.

(Contact: Engineering@c-nexco.co.jp)



An example of special support pattern in the weak ground

A Tunneling Project Near a Route in Service and Important Structures -Fujishiro Tunnel, Hanwa Expressway-

Souta IRIE — Kainan Construction Section Manager, Wakayama Construction Office, West Nippon Expressway Company Limited
Mamoru YUKIZAKI — Manager, Fujishiro Office, Osaka Branch Office, Tekken Corporation
Ryo HIRATA — Fujishiro Office, Osaka Branch Office, Tekken Corporation

Introduction

The north section of the Fujishiro Tunnel is the second phase tunnel of the project, extending 1151 m of the total tunnel length of 2136 m. The geology consists of black schist, green schist, quartz schist, serpentine and diabase.

This project has the following characteristics. First, there was fear that tunneling would have an impact on a power transmission line tower about 20 m high that is on a small ridge where the overburden depth above the tunnel is about 13 m. The behavior of the tower and surrounding ground was therefore measured in real time, and based on the measurement data, proper countermeasures against ground settlement were selected to excavate just beneath the tower.

Secondly, an emergency cross passage was planned, linking the first phase tunnel and this project, i.e., the second phase tunnel. Since the impact of blasting excavation on the first phase tunnel was anticipated, tunneling was carried out while measuring vibrations produced by blasting.

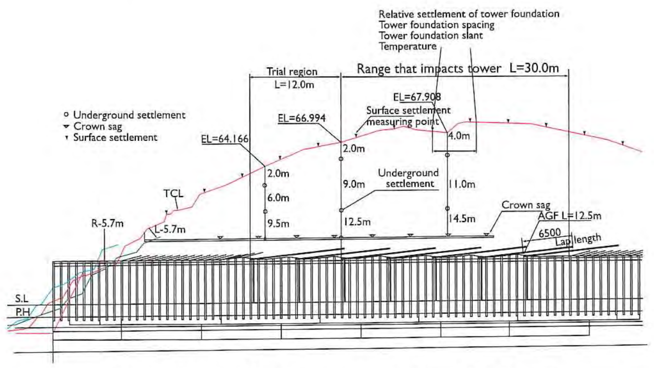
Tunneling just beneath the tower

The criterion for differential settlement of the tower foundation was set to a very rigorous standard of 3.0 mm or less. To satisfy this requirement, the zone of 30 m around the tower was set as the impact region, and the zone of 12 m preceding it as the trial region, and tunneling was implemented while confirming suitability of the construction method and necessity of additional countermeasures, through comparison between values obtained by 3D FEM analysis and measured data. Consequently, the AGF (all ground fastening) was utilized as an auxiliary method so that the differential settlement was limited to a minimal 0.8 mm, achieving safe tunneling without adversely affecting the tower.

Construction of the emergency cross passage

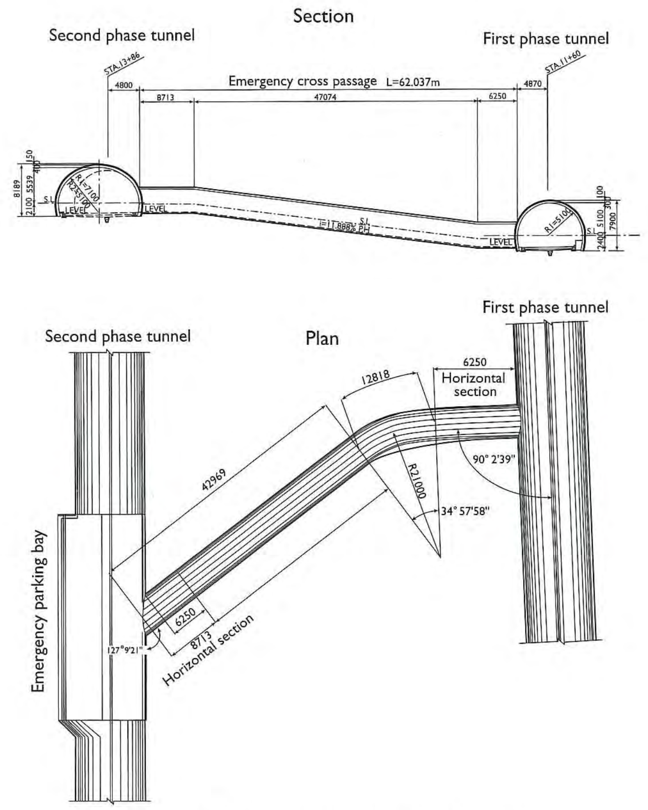
The emergency cross passage was driven from the second phase tunnel to the first phase tunnel in service. Blast vibration accelerometers were installed on the spot where the cross passage penetrates the first phase tunnel. A control reference (2 cm/sec) was set so that the lining would not be affected. If acceleration exceeding the control reference was anticipated, the powder amount of each blast delay was reduced (controlled blasting about 27 m), and the excavation method was changed to hydraulic wedge that does not have an impact due to vibration (rock fracture about 20 m). As a result, the cross passage was constructed without affecting the first phase tunnel.

(Contact: Engineering@c-nexco.co.jp)



Arrangement for measurements at the tower


Driving with rock fracturing



Location of the emergency cross passage

Different-diameter Mechanical Underground Docking and Right-angle Branching Shield Tunneling under High Groundwater Pressure

Isao OHNO — Assistant Section Manager, Seibu Construction Office Construction Section 2, Bureau of Waterworks Tokyo Metropolitan Government

Introduction

This project involves construction of water transmission and distribution pipelines extending about 2.1 km in Tokyo. A tunnel was planned to be driven with shield machines, to accommodate two pipelines, that is, a transmission pipeline and a distribution pipeline 1800 mm and 1000 mm in diameter respectively, made of ductile cast iron. The tunnel depth was to be 40 m in order to prevent interference with existing underground installations.

This project features three tunnels different in diameter (4000 mm, 2400 mm and 2000 mm) meeting together at a specified location (Fig.1). The conventional method used in such a case is to provide a shaft at the meeting point, and shield machines of the different diameters start from or arrive at the shaft. However, in the present project, constraints on the surface made it difficult to build a shaft, and so to reduce costs, a combination of two methods was used, which were "different-diameter mechanical underground docking" and "right-angle branching shield tunneling" without shaft construction. This technology enabled successful docking without soil improvement and without shaft.

Mechanical underground docking

In order to successfully join the shield tunnels by this method, position-check boring was made from the surface at a point 100 m ahead of the docking point, thereby determining the distance and direction of final excavation. This survey revealed the relative position between the shield machines, i.e., misalignment of 13 mm in the vertical direction and 16 mm in the horizontal direction. After the following shield had arrived at the specified position, the penetrating ring was pushed out from the following side, to be pressed against the receiving rubber of the preceding shield machine. Under groundwater pressure of 0.35 MPa, no water leaked through the interface between the penetrating ring and receiving rubber.

Right-angle branching shield tunneling

The auxiliary machine 2000 mm in diameter started from the main machine 4000 mm in diameter in the right-angle direction. First, excavation was executed with the head portion of the auxiliary machine divided into four sections placed in the main machine. The skin plate of the main machine was designed with an opening for starting the auxiliary machine. The opening was covered with a gate until the machine reached the branching point. At the branching point, the gate was rotated to open the portion that starts the auxiliary machine. Next, the intermediate and rear portions of the auxiliary machine were assembled inside the main machine to gradually push the auxiliary machine forward. By repeating these steps, the whole of the auxiliary machine was moved forward in about three weeks.

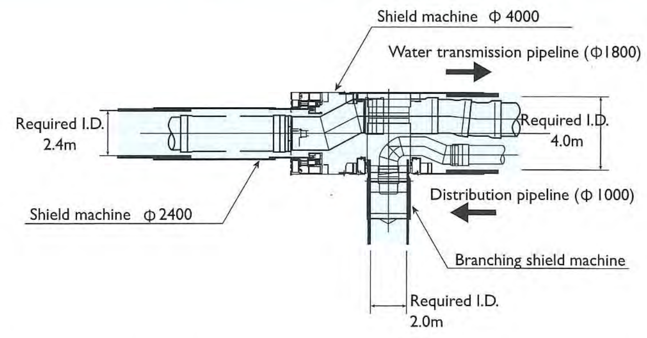


Fig. 1 Details of the underground docking and branching point

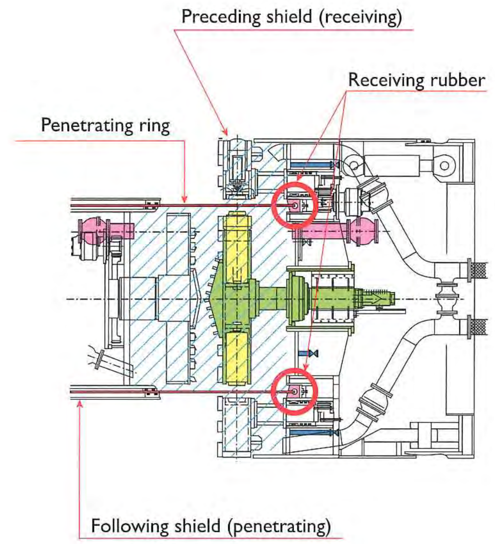


Fig. 2 Mechanical underground docking

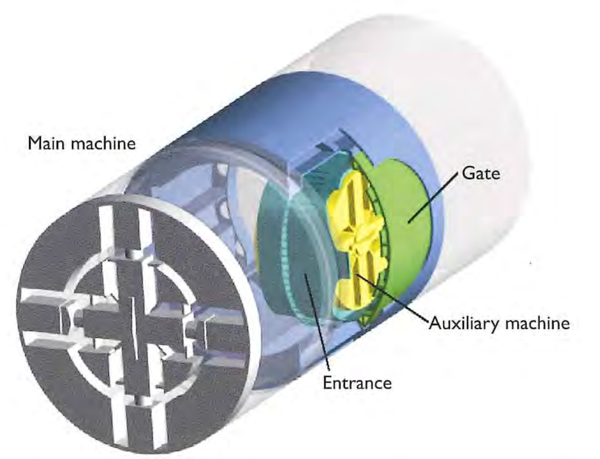


Fig. 3 Schematic of the right-angle branching shield tunneling

Mechanical Docking of the Long Shield Tunneling under Tokyo Bay

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Construction Department,
Tokyo Electric Power Company

Overview

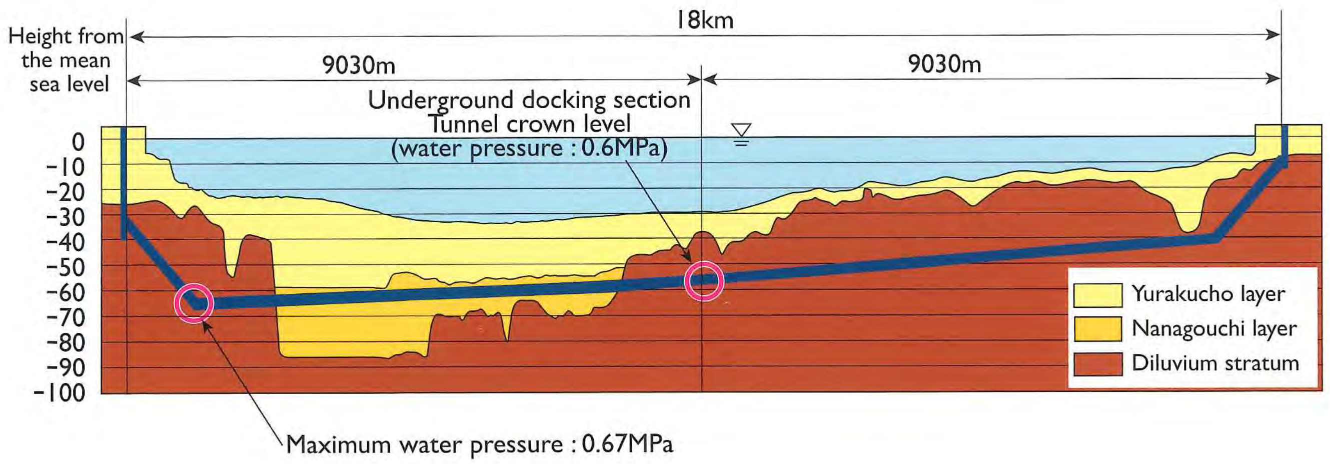
Tokyo Electric Power Company constructed a tunnel 18 km long traversing the Tokyo Bay, in order to efficiently and effectively supply liquefied natural gas to the thermal power plants located in the Tokyo Bay shore areas. The tunnel was driven with slurry shields (tunnel outer diameter of 3.44 m) from opposite sides of the Tokyo Bay, and the shields docked with each other at the midpoint below the Tokyo Bay seabed.

In this project, a distance of 9 km was driven without replacing the bits. Wear of the preceding and main bits was significantly smaller than the estimated amount. This result was achieved by the use of grade E3 tips excellent in both wear and shock resistances, and arrangement of the preceding and main bits in the same path, and by improved efficiency of soil intake with a larger cutter head opening ratio.

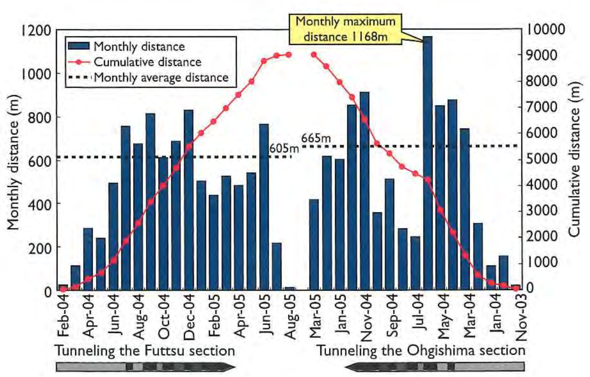
Other additional features were utilized in this project, including the segment joints that can be readily tightened merely by manipulation of the erector, and higher operation rate, more than 93%, recorded. The monthly advance was 665 m on the average and 1,168 m at maximum.

The shield machines that had started from the opposite sides of the Tokyo Bay, advanced 9 km each, and coupled with each other under water pressure as high as 0.6MPa, by the mechanical docking method.

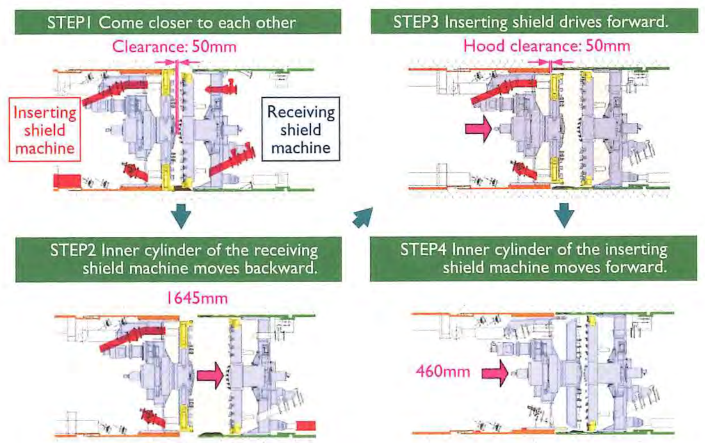
Each shield machine has an inner cylinder that slides inside the outer cylinder (main body of the shield machine). The receiving shield that arrives first retracts the inner cylinder, and the inserting shield pushes out the inner cylinder, thereby being mated with each other. This docking process was extremely complicated both in mechanism and work steps. Nevertheless, the docking was completed with almost no water leak.



Longitudinal section



Tunneling advance



Underground docking

Information-oriented Construction for the Omarugawa Underground Power House

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Summary of the project

The Omarugawa power plant, a pumped storage hydropower plant, is under construction in Miyazaki Prefecture. The upper dam and under dam are linked with an approximately 2.8 km water channel, constituting an effective water head of 646.2 m with a maximum power generation capability of 1,200MW. Excavation of underground power house was completed in February 2003, with 23 months spent since starting excavation, by the use of information-oriented construction focusing on the safety and economy.

The cavern for an underground power house is 24.0 m wide, 48.1 m high, with the maximum length of 188.0 m. The in-situ geology consists of hard granodiorite as bedrock (unconfined compressive strength approximately 170 MPa). The transversal profile of the cavern was warhead-shaped.

(1) Information-oriented construction

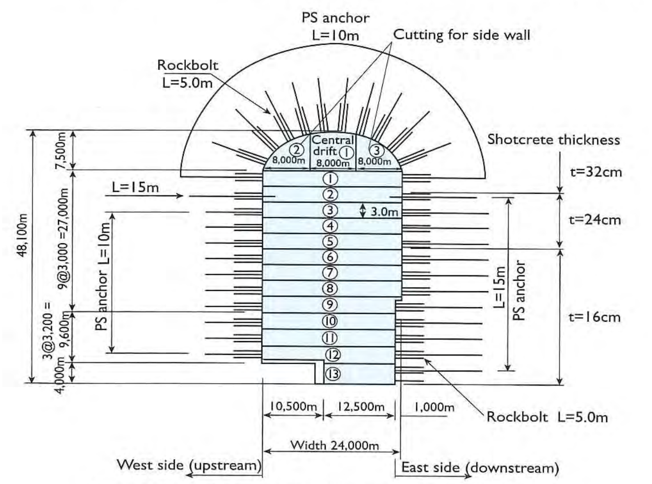
Cavern excavation was made by a NATM method, using shotcrete, rockbolt and PS anchors as support member. The movement of the bedrock was managed with an information-oriented construction based on underground in-situ instruments, capable of timely evaluating as well as analyzing the data on bedrock behavior, and of integrating such data into the design/construction process; the above data was collected by eight in-situ extensometers labeled from A to H in the longitudinal direction of the cavern, and by using anchor load meters and axial force meters for rockbolts.

(2) Bedrock behavior during excavation and reinforcement

The cavern was excavated with sixteen steps in total, that is, 3 steps for arch section, and 13 steps for sidewall (the bench cut step's length 3 m).

Prior to the excavation stage, examination was developed over prediction of deformation, and necessity, magnitude, quantity, etc., of bedrock reinforcing by the use of the data from in-situ instruments and two-dimensional FEM analysis. Based upon these steps, the regions predicted to be susceptible to significant deformation were minutely monitored, and effectively reinforced at bedrock sections.

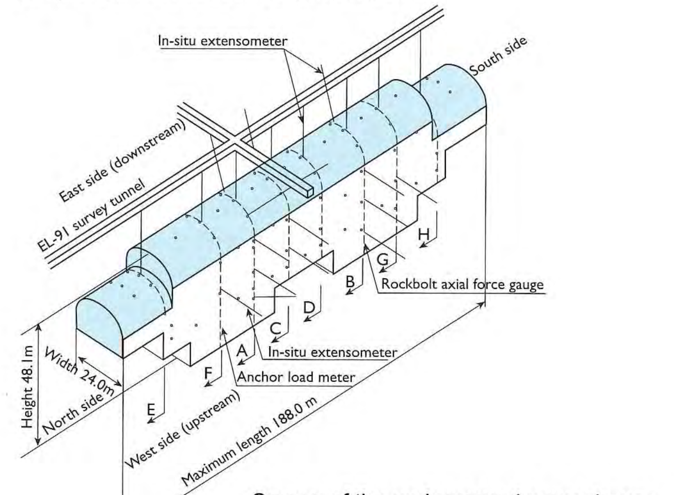
The arch was reinforced at an earlier stage, by placing additional PS anchors around the wedge-type key block, taking account that excavating this portion is made depending mainly on falling demolition, and that applying the reinforcement becomes difficult after the excavation of sidewalls. For the reinforcement of sidewalls, by limiting its scope to the bedrock block area, countermeasures were applied in appropriate timing, to a necessary quantity; paying attention to the fact that the prevailing demolition mode is rock sliding and that the demolition proceeds slower than in the arch section.



Support pattern and excavation step diagram

Conclusion

With the information-oriented construction we adopted, the countermeasure can be minimized and is limited to only the required locations. The bedrock did suffer no significant alteration, and the magnitude of the support can be reduced by 40% in comparison with the conventional method.



Cavern of the underground power house and configuration of in-situ instruments

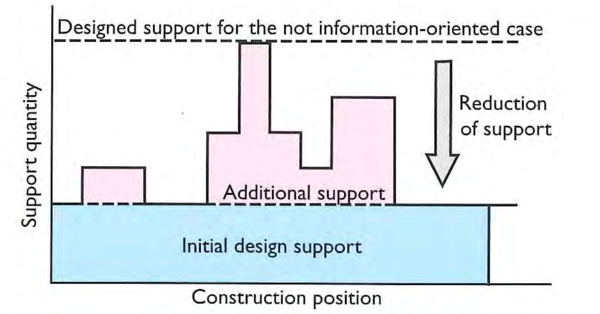
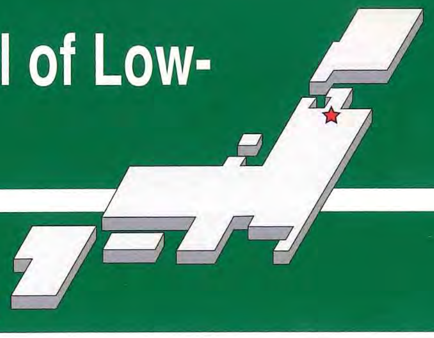


Image of an additional support by information-oriented construction

Test Cavern for Underground Disposal of Low-Level Radioactive Waste



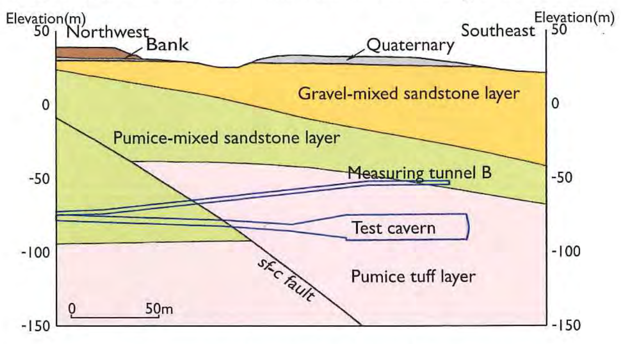
Atsunori TOMITA
Deputy General Manager
Development and Engineering Department,
Japan Nuclear Fuel Limited

Overview

The Federation of Electric Power Companies of Japan (FEPC) has planned construction of a new facility for underground disposal of Low-Level Radioactive Waste (LLW) with engineered barriers. The new facility will function as a repository for relatively higher LLW from nuclear power plant operations and core materials from decommissioned reactors.The new facility must have the following characteristics: (1) enough depth and mechanical stability so that general use of underground is not restricted i.e. 50-100 m in depth with no natural resources present, (2) a site with both sufficiently long ground water pathway and good hydraulic characteristics, (3) installation of adequate barriers in the storage area, (4) control of the site can be maintained for a few hundred years.

Japan Nuclear Fuel Limited (JNFL), which has been commissioned by FEPC, has conducted a feasibility study and detailed investigation inside the site in the northern part of the Mainland, about 700 km from Tokyo. The geology and ground water has been studied in detail since 2002 in order to collect various data for the safety review. As a part of the investigation, tunnels and a test cavern have been excavated to acquire knowledge of the mechanical stability of openings and the Excavation Disturbed Zone etc. The excavation of the 1 km long approach tunnel began in March 2003. Moreover, the large-scale test cavern was completed in June 2005. Prior to excavation of the test cavern, three monitoring tunnels were excavated within a 20 m vicinity of the test cavern and monitoring instruments were installed in order to examine the rock behavior.

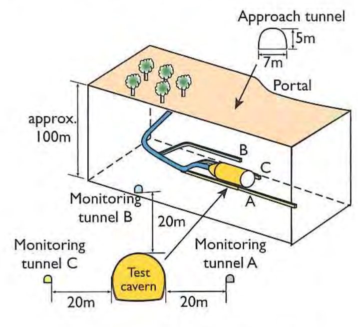
The geology around the test cavern mainly consists of marine sediment of the Miocene era. The cavern is located in a pumice tuff layer, which has 20 - 40 % of pumice with the diameter size ranging from several millimeters up to 10 cm and few existing cracks were observed by the borehole exploration and the excavation of the monitoring tunnels. This means the site is a satisfactory candidate site for the radioactive waste disposal. The cavern has an earth overburden coverage of approximately 100 m, and the competence factor of the rock, which is the ratio of rock strength to in situ stress, is smaller than two. This means the strength of the rock is low relative to in situ stress, and the site corresponds to the rock mass with relatively high rock stress.



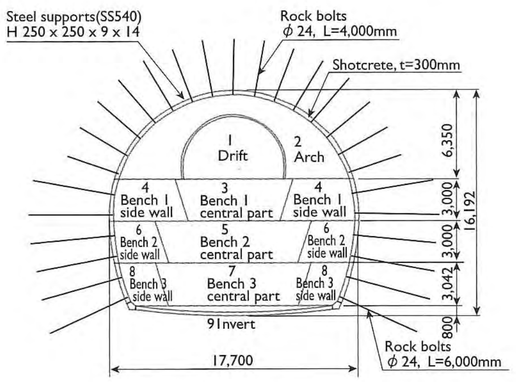
Geological section around the cavern

The test cavern is a space with a shape of three-centered circle; 17.7 m wide, 16.2 m high and 71.2 m long. It was excavated by using a boom-type excavating machine and other machines. Excavation was in the following order: drift (pilot tunnel) excavation, arch enlargement and three-step bench cut (about 3 m per bench). In the each bench, the central part was excavated first, followed by excavation of the sidewalls. The typical rock support system consists of shotcrete (300 mm thick), rock bolts (4 m long for arch and 6 m long for wall) and steel supports (H-shaped steel beam: 250 x 250 x 9 x14, ctc.1 m).

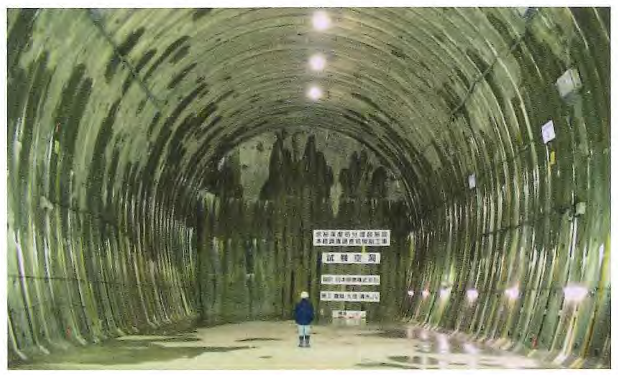
The detailed investigation was completed successfully in 2006. Currently, in order to move forward with the LLW underground disposal project, JNFL is preparing the basic design of the facility and the safety review documents based on the results of the detailed investigation.



Bird's-eye view of the site



Cross section of the test cavern



Test cavern

Damage and Restoration of Railway Tunnels Hit by the Niigataken Chuetsu-oki Earthquake

Tomoaki MORIYAMA
Manager,
Construction Department,
East Japan Railway Company

Introduction

The Niigataken Chuetsu-oki Earthquake of magnitude 6.8 occurred at around 10:13 on July 16, 2007.This earthquake entirely destroyed 1,024 houses and partially destroyed 5,250 houses. Infrastructure was also severely damaged, including the Kashiwazaki Kariwa nuclear power plant, and roads and railway structures.

Positional relationship of the tunnel with the epicenter

Three tunnels damaged are about 30 km from the epicenter, within about 5 km from the slip plane of the assumed earthquake source dislocation model.

Damages of the railway tunnels and restoration cases

The Daiichi Yoneyama Tunnel, which was most seriously damaged, is in the typical geology of soft sandstone, with the maximum overburden of about 66 m. It was a double track tunnel for a conventional railway, constructed by top heading with advancing drift, completed in 1968, 1,263 m long.

Of the total length of 1,263 m, two sections of 120 m and 10 m long respectively were seriously damaged. Compressive bending fractures occurred continuously in the crown, and the lining concrete partially spalled (spalls about 30 to 60 cm wide, 20 cm thick). In the extremely damaged zone, bending fractures in the crown, damage due to shear cracking of the lining concrete at the arch shoulder, and damage in the side walls took place (Photo 1).

For restoration, rockbolts (32 mm in diameter, 4.0 m long) were driven at intervals of 1.2 m (interval of existing steel supports) in the tunnel longitudinal direction. In order to reuse the existing lining by means of section repair and injection in cracks, the extremities of the section-repaired portions were cut at right angles with the tunnel section using concrete cutters, so that axial forces may be transmitted. (Fig.2)

The inside of the lining concrete repaired were covered with aramid fiber sheets to prevent spalling. Grout was injected into the cavities on the back of the lining. As final finish, FRP bands were placed and tightened with rockbolt plates. (Photo 2)

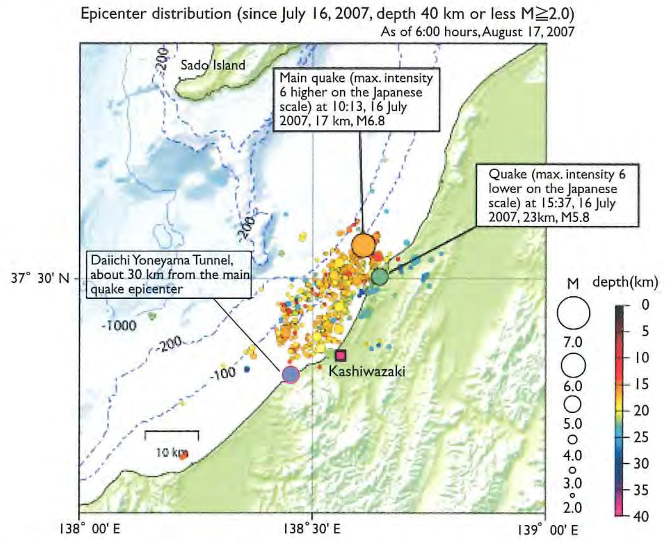


Fig. 1 Distribution of epicenters of Niigataken Chuetsu-oki Earthquake
(source: data in the web site of the Japan Meteorological Agency, modified)

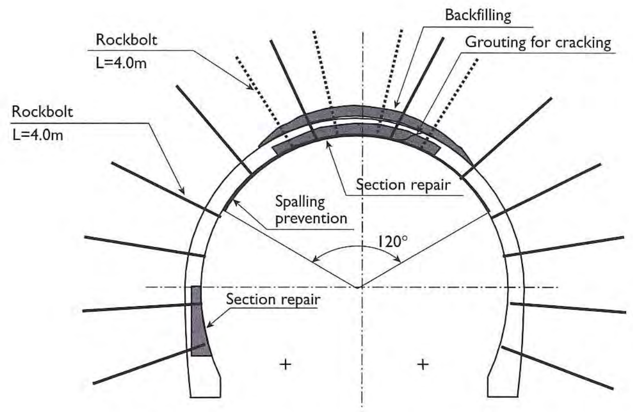


Fig. 2 Example of restoring pattern

Photo 1 Damage to the Daiichi Yoneyama Tunnel on the Shin-etsu Honsen railway

Photo 2 Restoration of the Daiichi Yoneyama Tunnel on the Shin-etsu Honsen railway

Innovations in Technology

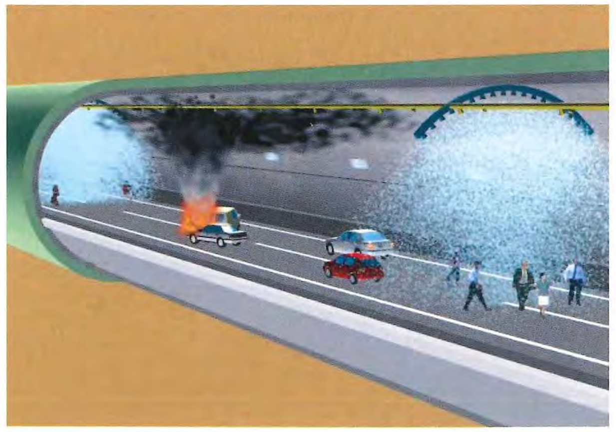
"Water Screen" Auxiliary System for Evacuation in Case of Fire in Tunnels

The Water Screen is a novel system that forms a screen of water by spraying water droplets about 200 μm in diameter from special nozzles placed at regular intervals on the ceiling. When a fire occurs in a tunnel, the Water Screen at each end of the fire zone is activated to prevent heat and smoke from spreading, and to catch and wash out harmful suspended particles, thereby offering improved evacuation environment for people trapped in the tunnel.

The basic performance of this system has been already validated by a test simulating a road tunnel of the sectional reduced scale of about 1/2. The Water Screen is capable of blocking about 80% of heat and smoke. Since the Water Screen forms a screen of water, it does not impede movement of people and vehicles, enabling smooth evacuation.

Addition of the Water Screen to the existing fire equipment such as water sprinklers in road tunnels, will further improve safety in evacuation.

Model test setup



Schematic of application in a road tunnel

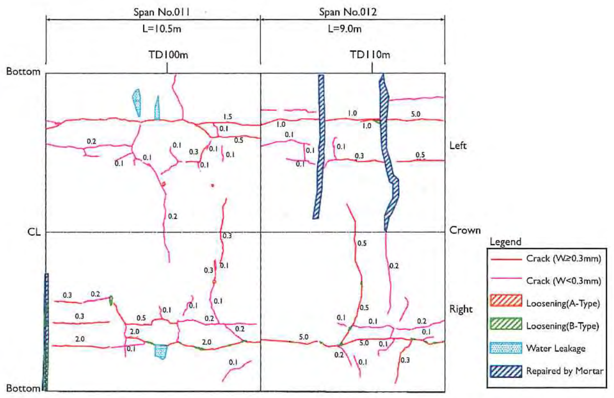
"KUMONOS" A Crack Measuring Instrument Using a Total Station with Integrated Crack Scale

"KUMONOS" is a novel instrument that measures the width and geometry of cracking in a structure accurately and rapidly. It is capable of measuring a crack 0.1 mm wide 20 m apart.

This system records geometry and position information of structures in the form of accurate 3D coordinate data. Data of measurements with an oblique angle are corrected to crack widths measured orthogonally. By the use of the dedicated application software and commercially available CAD, data obtained can be converted to CAD data for automatically drawing graphics.

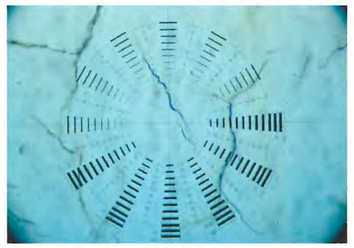
Measurements of cracks at high positions have been made conventionally with temporary scaffolds or elevated work platforms. However, KUMONOS measures such crack from the ground surface, thereby improving work safety and reducing work costs because scaffold costs, etc. are not necessary.

Since crack width and geometry can be monitored using 3D coordinate data, cracking is evaluated in a quantitatively accurate manner. The amount of repair can be calculated in detail, thereby enabling preparation of a reasonable repair plan. Furthermore, comparison of past and current records, evolution of cracking can be correctly grasped.



Developed view of damages of a tunnel

Measurement with KUMONOS



Measuring crack width by the integrated scale through lens

Innovations in Technology

Continuous Belt Conveyor U-turn Device

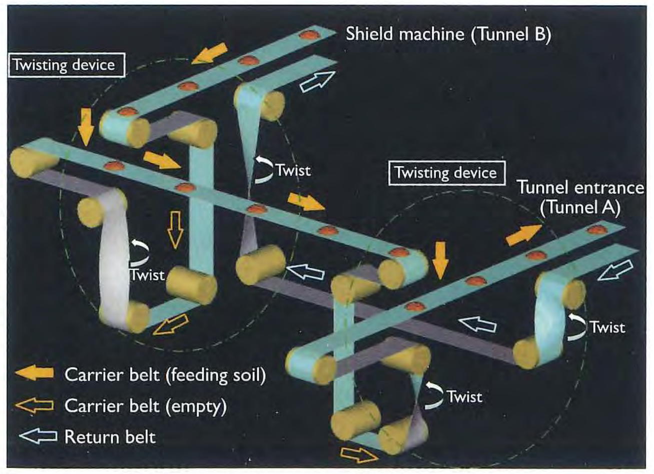
For constructing the twin subway tunnel with a single track for each direction, the recent trend is the use of a mud pressure shield machine to apply U-turn boring to reduce the cost.

We developed a new model of U-turn device with a continuous belt conveyor for muck handling in the frame work of a mud pressure shield tunneling method, and used it in the actual tunneling.

The most remarkable feature of this U-turn device is the development of a direction-changing mechanism depending on the twisting technology conventional belt conveyors already have; with this, the single belt conveyor can be designed to work as usually, but at required positions, to function as a relay conveyor. The U-turn device is composed of two twisting systems, and by the pulley in the system, the belt is twisted 90 degrees to change the operation direction to a right angle. Once passing another twisting device the conveyor changes its direction by a right angle, so that it can be U-turned. With this system, the following advantages are achieved;

- The belt conveyor can perform its U-turn direction change regardless of the distance between tunnels for mucking, and the space available
- The system can be adaptable for L-shaped tunnels and crank-shaped tunnels.

With these strong points, it is expected that the system can extend its applicability not only for shield tunneling but also for urban area civil works to handle the muck even in a restricted work space, hopefully leading to more cost reduction and improved tunneling performance.



Schematic diagram of U-turn device

COMPASS Method

The COMPASS method is a technique for constructing small-section crossing structures such as walkways and channels, beneath railway tracks and roads.

This method consists of the following steps. The ground is cut with wires, and four-sided steel plates are inserted, tracing the perimeter of the structure (Fig.1, Photo 1). While the inside of the steel plate walls is excavated and supports (H steel shapes) are erected, concrete is placed to build the structure.

This method has the following advantages.

1) Steel plates (22 mm thick) are placed into the interstices in the ground cut with wires, to surround the space to be excavated. This technique keeps the upheaval and the subsidence of the ground small.

2) The cutting wire is capable of cutting gravel and boulders. Even if an obstacle (ex concrete) exists in the ground, the method is able to cut without any impact on the ground surface.

3) While digging the ground, the sliding blade supports the inside of the steel plates and the point of the sliding blade penetrates ahead of the device, ensuring stability of ground.

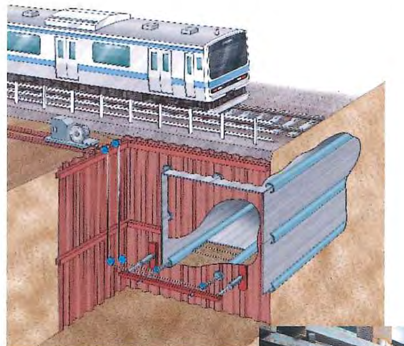


Fig. 1 Overview of the COMPASS (placing steel plates)

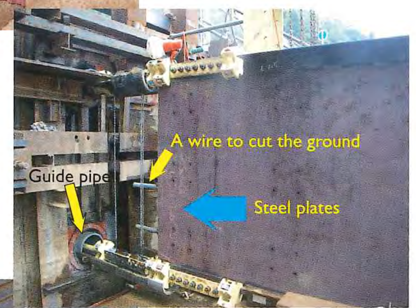


Photo 1 Installing the side steel plate

Photo 2 The sliding blade

Innovations in Technology

Environmentally Friendly Tunnel Construction

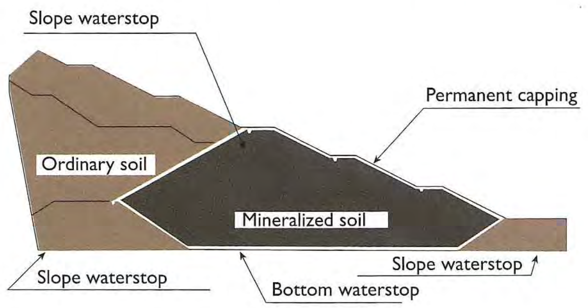
The Hakkoda Tunnel on the Tohoku Shinkansen Railway, 26 km long, the longest in the world among land tunnels with double tracks, excavation was entirely completed by February 2005. Mineralized altered rock is distributed in the vicinity of the site. There is a fear that this type of rock would react with oxygen in groundwater and air to elute heavy metal and acid water, which may adversely affect the environment. This was the reason why proper sorting and treatment of excavated muck were essential.

Through study on these site conditions, muck was disposed of as follows in an environmentally friendly and economic manner. Muck containing mineralized altered rock was sorted out by a unique sorting criteria and management method, and placed in a "controlled landfill site" (shielded type). The remaining muck was placed in an "ordinary landfill site."

The entire controlled landfill site was protected with measures to stop water using double-layers of impervious sheets, which can be extended according to the volume of muck. This controlled site was arranged within the landfill site, which included the ordinary landfill site.

This type of large-scale disposal system of excavated muck will contribute to environmental conservation around tunneling projects in the future, particularly sites that have been subject to mineralization.

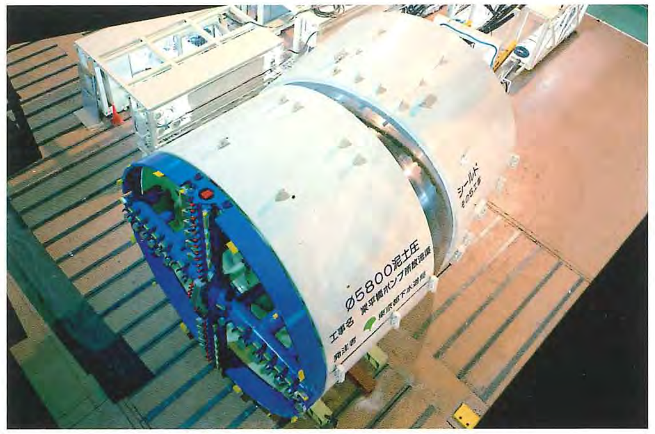
Impervious sheet placed at the bottom



Section of the landfill site

Shield Machine for Sharp Curve and Steep Slope Tunneling

One construction project of the Tokyo Metropolitan sewerage system includes in its route a sharp curve in plane R=20 m, a sharp curve in longitudinal section R=60 m, and a steep slope i=20%. The shield machine (OD=5800 mm) for this project is structured to follow an angle of 11.1 degrees in the transversal direction and 4.0 degrees in the vertical direction. Segments for the section of sharp in-plane curve have an outer diameter 70 mm smaller than that of the standard segment, in order to avoid interference between the shield tail and segment. When driving in the sharp curve section, segments with bag were used to prevent meander and displacement due to thrust component toward the outside of the curve. During driving in the sharply curved in-longitudinal-section zone, segments of high rigidity were used to counteract thrust component downward. In the steep slope section, earth pressure on the face, which varies from ring to ring, was controlled to curb bursting and, while changing the additive injection rate at the face and behind the screw, air lifting by a compressor was utilized to deter clogging. Pinion gear and pin lock were adopted to prevent the battery locomotive from overrunning in the steeply inclined section, and wagons capable of following changes in inclination were employed to prevent dropping of material during transport.



Articulated structure of the shield machine

Segment with bag (view of bag filling)

General Aspects of Tunneling in Japan

Trend of Construction Investment in Tunnels and Underground Spaces

The total amount of construction investment in tunnels and underground spaces in Japan increased rapidly until 1995, but since 1995 it has been on the downturn due to the continuing government curbs on public investments. Figure 1 shows trends in volume of work under construction, divided according to the purposes of tunnels and underground spaces in Japan. In general, the amount has decreased since 1995 and now is at the level around 1988.

Figure 2 shows the makeup of contracted amounts of different project purposes in 2007. The largest was road at 49%, followed by railway at 26%, water channel at 14% and others at 11%.

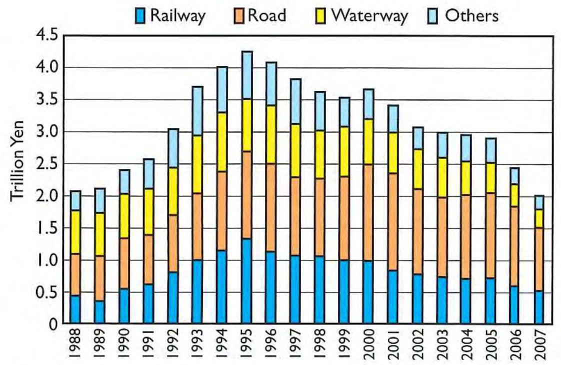


Fig. 1 Trend of construction investment in tunnels and underground space

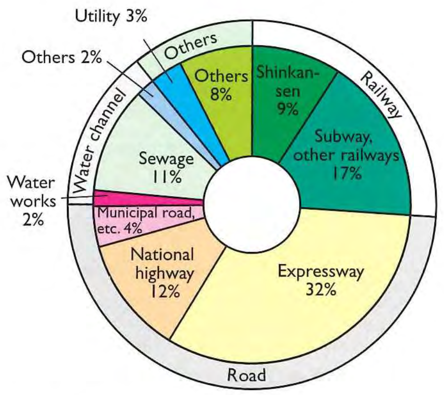


Fig. 2 Ratio of contractual amount by project purpose

Trends of Tunneling Method

Figure 3 shows trends in the number of tunnel construction sections by tunneling method (conventional/NATM, shield method, etc.) and changes in their proportion. The ratio of the conventional method is the highest, accounting for 30% to 50% of the total and still increasing, followed by the shield method, leveling off in the range 20% to 30%. The ratio of pipe jacking projects has dipped, accounting for 13%, and the cut-and-cover levels off at around 10%.

The increase of projects by the conventional method is attributable to widened range of economic application of this method because of technological development such as various auxiliary methods.

Figure 4 illustrates the percentages of different construction methods and those of excavation methods. The conventional method accounts for 50% of the total, for which blasting is most frequent, 56%. The shield method is 24%, which is subdivided into 22% of slurry shield and 69% of mud slurry shield and 8% of earth pressure balanced shield.

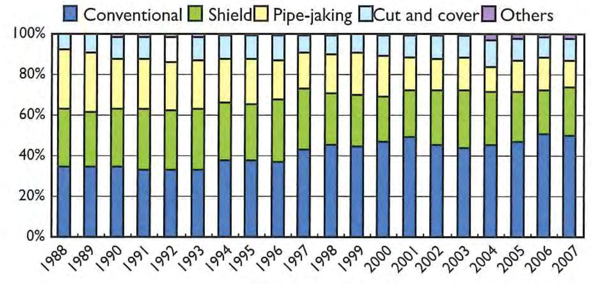


Fig. 3 Ratio of tunnels by excavation method (No. of tunnels)

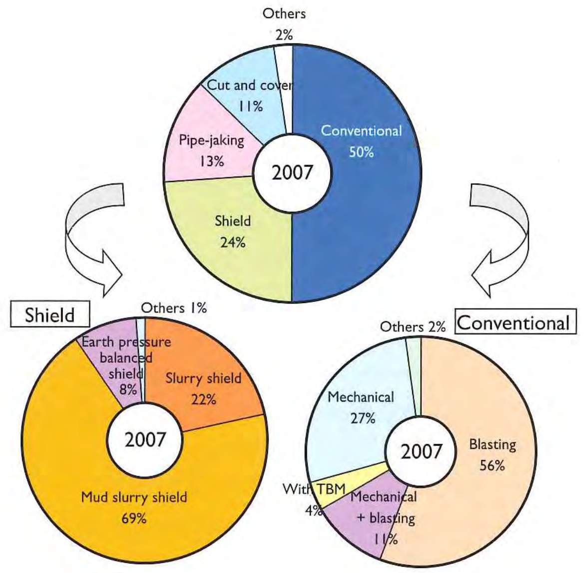


Fig. 4 Breakdown of construction and excavation methods

Overseas Tunnel Construction by Japanese Contractors

Figure 5 is the change in contract amounts of overseas tunnel construction projects by JTA members. The amount has been gradually increasing since 1989.

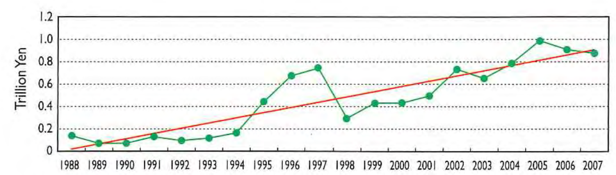


Fig.5 Overseas tunnel construction by Japanese contractors

Public Corporations, Local Authorities and Owner Companies

Central Nippon Expressway Company Limited
2-18-19, Nishiki, Naka-ku, Nagoya-shi, Aichi 460-0003
TEL: 52-222-3440 FAX: 52-232-3736
E-mail: Engineering@c-nexco.jp http://www.c-nexco.co.jp/english/

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

Hanshin Expressway Company Limited
4-1-3, Kyutaro-machi, Chou-ku, Osaka-shi, Osaka 541-0056
TEL: 6-6252-8121 FAX: 6-6252-4583
E-mail:gijyutsu@hanshin-exp.co.jp http://www.hanshin-exp.co.jp

Japan Railway Construction, Transport and Technology Agency
Yokohama I-land Tower, 6-50-1, Honcho, Naka-ku, Yokohama-shi, Kanagawa 231-8315
TEL: 45-222-9101 FAX: 45-222-9089 http://www.jrtt.go.jp/

Metropolitan Expressway Co., Ltd.
1-4-1 Kasumigaseki, Chiyoda-ku, Tokyo 100-8930
TEL: 3-3539-9442 FAX: 3-3503-1806
http://www.shutoko.jp/

Nippon Expressway Research Institute Co., Ltd.
1-4-1, Tadao, Machida-shi, Tokyo 194-8508
TEL: 42-791-1968 FAX: 42-791-3717
E-mail: ri-info@ri-nexco.co.jp http://www.ri-nexco.co.jp/

Tokyo Electric Power Co., Inc.
1-1-3, Uchisaiwai-cho, Chiyoda-ku, Tokyo 100-8560
TEL: 3-6373-1111 FAX: 3-6373-4369
http://www.tepco.co.jp

Tokyo Metro Co., Ltd.
3-19-6, Higashi-Ueno, Taito-ku, Tokyo 110-8614
TEL: 3-3837-7132 FAX: 3-3837-7112
http://www.tokyometro.jp/index.html

Societies and Associations

Japan Railway Technical Service
2-27-8, Hongo, Bunkyo-ku, Tokyo 113-0033
TEL: 3-5684-3171~3179 FAX: 3-5684-3170/3180
E-mail: jarts-kaigai@tiger.odn.ne.jp http://www.jarts.or.jp/en/index.html

General Contractors

Asunaro Aoki Construction Co., Ltd.
2-14-5, Shiba, Minato-ku, Tokyo 105-0014
TEL: 3-5419-1011 FAX: 3-5419-1016
E-mail: koho@aaconst.co.jp http://www.aaconst.co.jp

Daiho Corporation
1-24-4, Shinkawa, Chuo-ku, Tokyo 104-8289
TEL: 3-3297-7008 FAX: 3-3553-6935
E-mail: info@daiho.co.jp http://www.daiho.co.jp

Hazama Corporation
2-2-5, Toranomon, Minato-ku, Tokyo 105-8479
TEL: 3-3588-5700 FAX: 3-3588-5755
E-mail: terauchi@hazama.co.jp http://www.hazama.co.jp

IWATA CHIZAKI INC.
17-2, Higashi, Kita 2-jo, Chuo-ku, Sapporo-shi, Hokkaido 060-8630
TEL: 11-221-2221 FAX: 11-222-7682
http://www.iwata-gr.co.jp/

JDC Corporation
4-9-9, Akasaka, Minato-ku, Tokyo 107-8466
TEL: 3-3403-3311 FAX: 3-5410-5808
E-mail: jdc-pr@n-kokudo.co.jp http://www.n-kokudo.co.jp

Kajima Corporation
6-5-11, Akasaka, Minato-ku, Tokyo 107-8348
TEL: 3-5544-0666 FAX: 3-5544-1725
http://www.kajima.co.jp

Konoike Construction Co., Ltd.
3-4-5, Umeda, Kita-ku, Osaka-shi, Osaka 530-8517
TEL: 6-6343-3500 FAX: 6-6343-3190
http://www.konoike.co.jp/

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Kumagai Gumi Co., Ltd.
2-1, Tsukudo-cho, Shinjuku-ku, Tokyo 162-8557
TEL: 3-3260-2111 FAX: 3-5261-5576
http://www.kumagaigumi.co.jp/

Maeda Corporation
2-10-26, Fujimi, Chiyoda-ku, Tokyo 102-8151
TEL: 3-5276-9471 FAX: 3-5276-9452
http://www.maeda.co.jp/

Obayashi Corporation
Shinagawa Intercity Tower B, 2-15-2, Konan, Minato-ku, Tokyo 108-8502
TEL: 3-5769-1303 FAX: 3-5769-1970
http://www.obayashi.co.jp

Okumura Corporation
2-2-2, Matsuzaki-cho, Abeno-ku, Osaka-shi, Osaka 545-8555
TEL: 6-6621-1101 FAX: 6-6623-7692
http://www.okumuragumi.co.jp

PENTA-OCEAN CONSTRUCTION CO., LTD.
2-2-8, Koraku, Bunkyo-ku, Tokyo 112-8576
TEL: 3-3817-7181 FAX: 3-3817-7642
http://www.penta-ocean.co.jp/

Shimizu Corporation
Seavans South, 1-2-3, Shibaura, Minato-ku, Tokyo 105-8007
TEL: 3-5441-0566 FAX: 3-5441-0510
http://www.shimz.co.jp

Sumitomo Mitsui Construction Co., Ltd.
6F, Sumitomo Nakanosakaue Bldg., 1-38-1, Chuo, Nakano-ku, Tokyo 164-0011
TEL: 3-5332-7203
http://www.smcon.co.jp/

TAISEI CORPORATION
1-25-1, Nishi-Shinjuku, Shinjuku-ku, Tokyo 163-0606
TEL: 3-5381-5283 FAX: 3-5381-5295
http://www.taisei.co.jp

Takenaka Civil Engineering & Construction Co., Ltd.
1-1-1, Shinsuna, Koto-ku, Tokyo 136-8570
TEL: 3-6810-6200 FAX: 3-6660-6303
http://www.takenaka-doboku.co.jp

TEKKEN CORPORATION
2-5-3, Misaki-cho, Chiyoda-ku, Tokyo 101-8366
TEL: 3-3221-2131 FAX: 3-3265-3776
E-mail: webmaster@tekken.co.jp http://www.tekken.co.jp

Toda Corporation
1-7-1, Kyobashi, Chuo-ku, Tokyo 104-8388
TEL: 3-3535-1354 FAX: 3-3562-2909
http://www.toda.co.jp

TOKYU CONSTRUCTION CO., LTD.
1-16-14, Shibuya, Shibuya-ku, Tokyo 150-8340
TEL: 3-5466-5272 FAX: 3-3797-7547
E-mail: webmaster@tokyu-cnst.co.jp http://const.tokyu.com/

Toyo Construction Co., Ltd.
2-43, Aomi, Koto-ku, Tokyo 135-0064
TEL: 3-6361-5450 FAX: 3-5530-2901
http://www.toyo-const.co.jp/

Speciality Contractors

Japan Foundation Engineering Co., Ltd.
15-17, Sakuragaoka-cho, Shibuya-ku, Tokyo 150-0311
TEL: 3-3476-5701 FAX: 3-3476-4551
E-mail: gijutsu@jafec.co.jp http://www.jafec.co.jp/

SANSHIN CORPORATION
1-2-7, Koraku, Bunkyo-ku, Tokyo 112-0004
TEL: 3-3816-2151 FAX: 3-3816-2178
E-mail:sales@sanshin-corp.co.jp http://www.sanshin-corp.co.jp

Seiken Co., Ltd.
1-12-14, Koishikawa, Bunkyo-ku, Tokyo 112-0002
TEL: 3-5689-2351 FAX: 3-5689-2361
E-mail: touketsu-eigyou@seikenn.co.jp http://www.seikenn.co.jp

Yoshioka Corporation
41-2, Gunge-shinmachi, Takatsuki-shi, Osaka 569-1136
TEL: 72-681-1861 FAX: 72-681-1866
E-mail: info@e-yoshioka.com http://www.e-yoshioka.com/

Consulting and Engineering Firms

Japan Transportation Consultants, Inc.
7-11-1, Ueno, Taito-ku, Tokyo 110-0005
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11-9, Nihonbashi-kodenmacho, Chuo-ku, Tokyo 103-0001
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OYO Corporation
43 Miyukigaoka, Tsukuba-shi, Ibaraki 305-0841
TEL: 29-851-6621 FAX: 29-851-6964
E-mail: kikaku@oyonet.oyo.co.jp http://www.oyo.co.jp/

Pacific Consultants Co., Ltd.
1-7-5, Sekido, Tama-shi, Tokyo 206-0011
TEL: 42-372-0111 FAX: 42-372-2201
http://www.pacific.co.jp/

Road Engineering Corporation
5-24-7, Nishi-Nippori, Arakawa-ku, Tokyo 116-0013
TEL: 3-3891-0711 FAX: 3-3891-0701
E-mail: info@road-eng.co.jp

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Atlas Copco K.K.
11F, Sumitomo Fudosan Shiba Bldg., 4, 2-13-4, Shiba, Minato-ku, Tokyo 105-0014
TEL: 3-5765-7890 FAX: 3-5765-3199
E-mail: sales.cmt@jp.atlascopco.com http://www.atlascopco.co.jp/

BASF Pozzolith Ltd.
3-16-26, Roppongi, Minato-ku, Tokyo 106-0032
TEL: 3-3582-8814 FAX: 3-3583-3800
http://www.pozzolith.basf.co.jp

C.I. KASEI CO., LTD.
1-18-1, Kyobashi, Chuo-ku, Tokyo 104-8321
TEL: 3-3535-4568 FAX: 3-3535-4542
http://www.cik.co.jp

DENKI KAGAKU KOGYO KABUSHIKI KAISHA
Nihonbashi Mitsui Tower, 2-1-1, Nihonbashi-muromachi, Chuo-ku, Tokyo 103-8338
TEL: 3-5290-5558 FAX: 3-5290-5085
E-mail: 010313@denka.co.jp http://www.denka.co.jp

FURUKAWA ROCK DRILL CO., LTD.
2-3-14, Nihonbashi-muromachi, Chuo-ku, Tokyo 103-0022
TEL: 3-3231-6966 FAX: 3-3231-6993
E-mail: jumbo@furudril.co.jp http://www.furukawarockdrill.co.jp/

Kayaku Japan Co., Ltd. (Explosives Manufacturer)
9F, KFC Bldg., 1-6-1, Yokoami, Sumida-ku, Tokyo 130-0015
TEL: 3-5637-0902 FAX: 3-5637-0939
E-mail: takaaki.torikai@kayakujapan.co.jp

MITSUBISHI HEAVY INDUSTRIES TUNNELING MACHINERY & GEOTECHNOLOGY CO., LTD.
2-16-5, Konan, Minato-ku, Tokyo 108-8215
TEL: 3-6716-4128 FAX: 3-6716-5833
E-mail: minoru_hokari@kbg.kobe.mhi.co.jp

Komatsu Ltd.
2-3-6, Akasaka, Minato-ku, Tokyo 107-8414
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E-mail: webmaster.ce@komatsu.co.jp

Orica Japan Co., Ltd.
7F, Toranomon Misu Building, 3-7-11, Toranomon, Minato-ku, Tokyo 105-0001
TEL: 3-5777-4681 FAX: 3-5777-4682
E-mail: kiminobu.yokoyama@orica.com http://www.orica.com

Sandvik Mining and Construction Japan K.K.
6F, Kyoritsu Shin-Yokohama Bldg., 2-15-2, Shin-Yokohama, Kohoku-ku, Yokohama-shi, Kanagawa 222-0033
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E-mail: koki.sakurai@sandvik.com
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Taiheiyo Materials Corporation
4-8-15, Nihonbashi-honcho, Chuo-ku, Tokyo 103-0023
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Memo