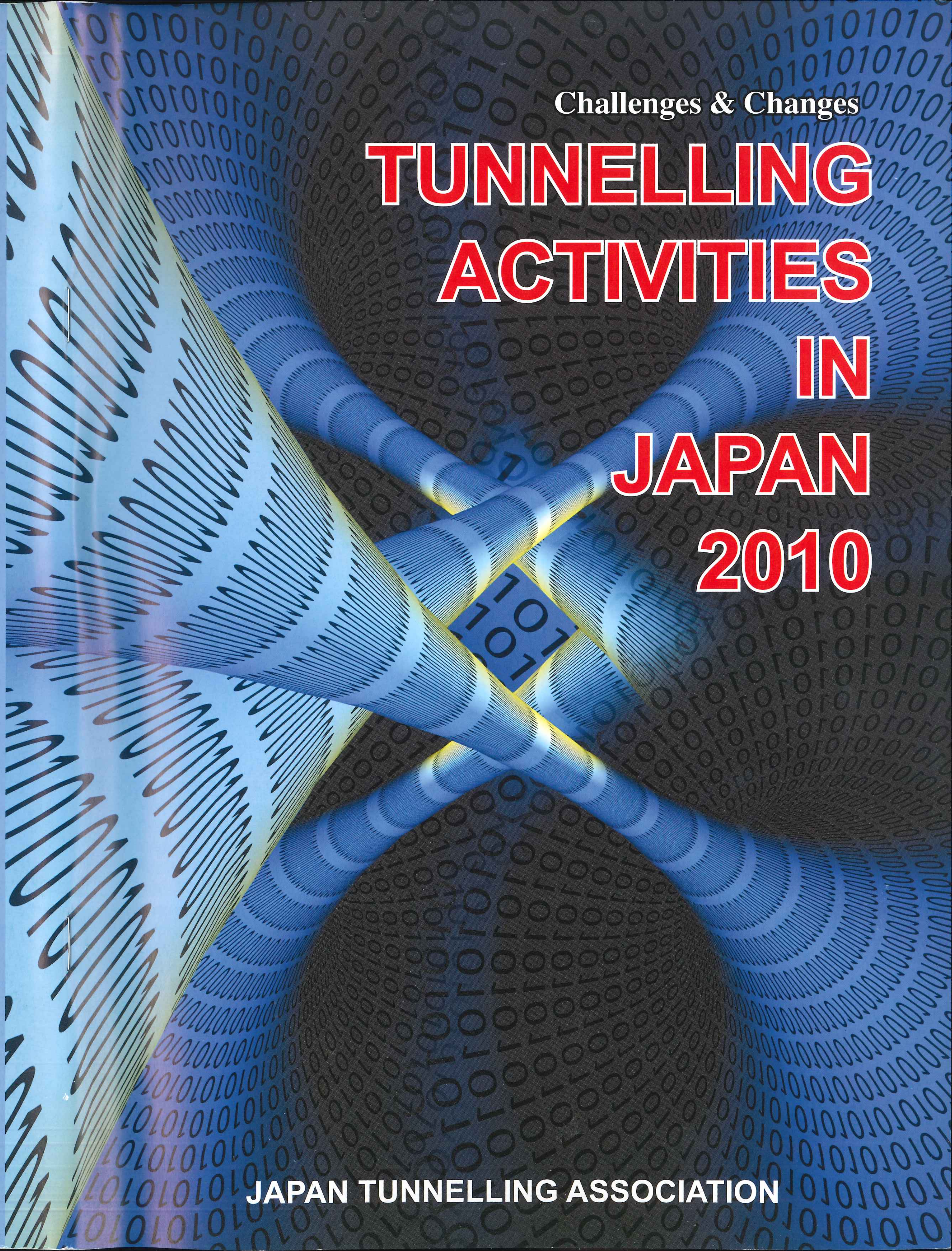
Japan Tunnelling Association
Shinko Dai-ichi Bldg., 14-7, Shintomi 2-chome, Chuo-ku, Tokyo 104-0041, Japan.
TEL:(+81)-3-3553-6174 FAX:(+81)-3-3553-6145
E-mail: jta@japan-tunnel.org
http://www.japan-tunnel.org



Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2010

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 2010 edition of Tunnelling Activities in Japan, biennial publication of Japan Tunnelling Association. Despite the fact that in recent years tunnel construction projects in Japan are on the downturn, our country remains one of the outstanding global leaders in terms of tunnel construction volume.

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.

佐藤信彦

Nobuhiko SATO

President

Japan Tunnelling Association

INDEX

Plans for the Hokkaido Shinkansen and Utilization of SENS - Tsugaru Yomogita Tunnel -

Masaaki HASEGAWA
Director of 1st Construction Division
Tohoku Shinkansen Construction Bureau
Japan Railway Construction, Transport and Technology Agency

1. Overview of the Hokkaido Shinkansen

The network of high-speed railway lines in Japan known as "Shinkansen" is in the process of expanding through construction of lines in various regions with the objective of connecting the major cities in the country. The Tohoku Shinkansen, which runs north from Tokyo, will be extended by approximately 80 km, and it will reach Aomori City, the capital of Aomori Prefecture, on the northern edge of the Honshu Island in 2010.

The Hokkaido Shinkansen is an extension, currently under construction, of the Tohoku Shinkansen from Aomori across the sea into Hokkaido. It includes the longest undersea tunnel in the world, the Seikan Tunnel, which has a total length of 53.85 km. Construction of the Seikan Tunnel began in 1964, and in 1988 it was opened for operations as part of the Tsugaru-Kaikyo Line. Currently, it is used by conventional express trains and freight trains. As a high-volume high-speed transportation system, the Shinkansen uses larger train cars than narrow-gauge railway lines and a dedicated structure, in which the track width, signal system and other facilities differ from those in narrow-gauge lines. However, the construction plans for the section that includes the Seikan Tunnel envisioned shared use of the tunnel by narrow-gauge and Shinkansen railways, and from the very beginning the line was built according to specifications that allow it to accommodate Shinkansen trains. As you can see from the diagram in the bottom right corner of Fig. 1, simply adding one extra track will enable Shinkansen trains to traverse the tunnel.

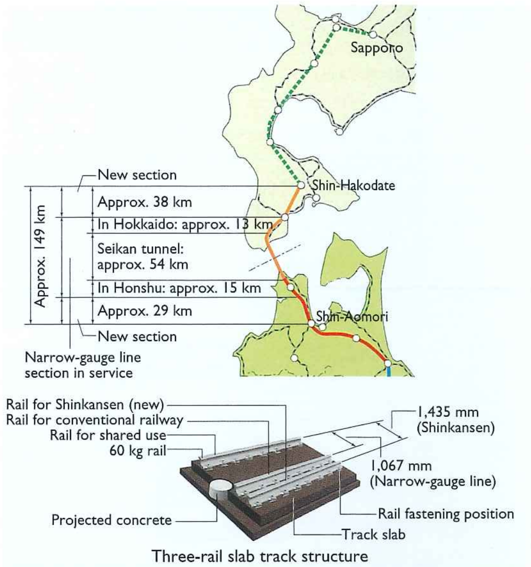


Fig. 1 Map of the Shinkansen network and a diagram of a three-rail slab track structure

2. SENS method used in the planning of the Tsugaru Yomogita Tunnel

The length of the structure for exclusive use by Shinkansen trains that will be constructed from Aomori Station on the Honshu side to the section for shared use is approximately 29 km. According to the construction plans, it includes 11 tunnels with a total length of approximately 7 km. All these tunnels are below the groundwater level, and the geology of the area where they will be constructed consists mainly of unconsolidated and semi-consolidated medium- to coarse-grained sandstone with a significant lateral displacement. When the tunnel in the section for shared use was excavated back in the 1980's, face collapses induced by sediment discharges occurred often, so it was expected that the construction work in this project, too, would be quite difficult. Furthermore, the portals of all 11 tunnels are located in a mountainous area several kilometers away from any arterial roads, so high costs for building of roads for construction purposes and auxiliary construction methods were anticipated in the budget. That is why, the longitudinal slope in the section of six of the tunnels was modified, and the plan was changed to make this section into a new single tunnel with a length of approximately 6 km. Also, it was decided to utilize mechanized construction by SENS (a cast-in-place concrete lining support system that uses shield machines), a system that had been successfully used in similar water bearing unconsolidated grounds in the construction of the Tohoku Shinkansen and that is characterized by outstanding safety, construction properties and economic efficiency.

The maximum monthly advance recorded with SENS in the construction of the Tohoku Shinkansen was 173 m/month. In the present construction project, various improvements were implemented in order to enable even faster excavation. These improvements include increase of the number of concrete pumps, and widening of the inner formwork. Furthermore, in order to build lining in the conditions with a maximum water pressure of 0.4 MPa, a concrete mixture with good workability and anti-washout underwater properties was developed. Also, the structure of the inner formwork that was to be used repeatedly was improved to avoid the occurrence of sheare force in the joints between pieces, and thus to make assembly and dismantlement work easier and safer. Based on these improvements, excavation work was launched in November 2009.

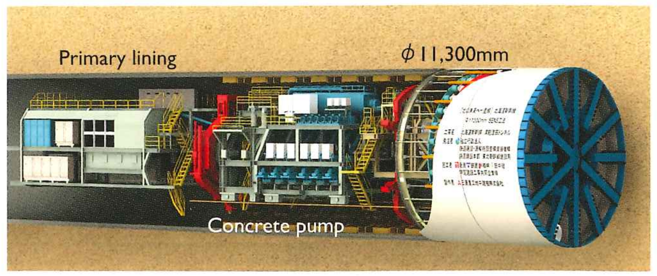


Fig. 2 SENS machine

Tunneling Technique Suitable for a Specific Geological Formation Featuring Extreme Swelling Tendencies with High-Pressure Aquifer - Iiyama Tunnel on the Hokuriku Shinkansen Railway -

Hideki HAGIWARA
Director of 2nd Construction Division
Hokuriku Shinkansen Construction Bureau
Japan Railway Construction, Transport and Technology Agency

1. Summary

This long tunnel of about 22 km is located in a Fossa Magna zone.

The ground around the tunnel route is an unconsolidated swelling ground with high-pressure aquifer, comprising several fold axes and vertical faults, and inflammable gas. An original tunneling technique and a new technique specifically engineered for this geological formation were used for excavation of this tunnel.

Photo 1 Deformation of the support

2. Original tunneling technique and new technique

1) Establishment of an original technique with multiple supports specifically engineered for this tunneling project in swelling ground

In the traditional tunneling practice, if the tunnel bore section is reduced as a result of swelling of the ground, the planned section is achieved by re-cutting with replacement of the supports. In the present project, a large deformation margin was provided, predicting displacements, to allow for a certain displacement of the 1st layer supports installed at the face, and the 2nd and succeeding supports were installed with a planned time delay behind the face. This practice maintained the integrity of the supports and limited the convergence to a small value.

2) Development of a face control technique for unconsolidated ground with high-pressure aquifer

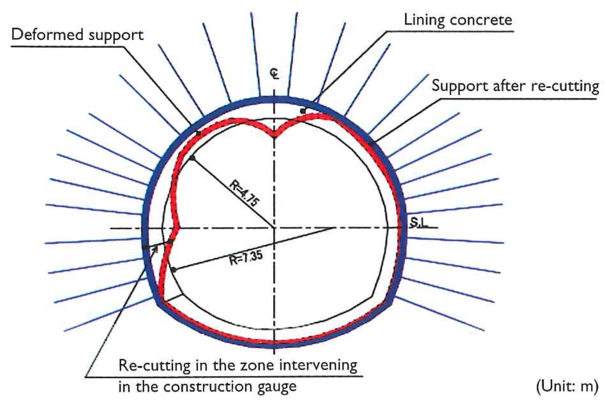


Fig. 1 Conventional method (replacing of support)

For the purpose of geological verification ahead of the face, drainage and water-ingress control, the tunnel was bored in three stages (1/ advanced boring approx. 200 m long, 2/ advanced middle-length boring approx. 100 m long, 3/ short boring 15 m long for verification just before excavation). Based on the results obtained, a face control technique has been developed, evaluating water-ingress pressure and geological properties.

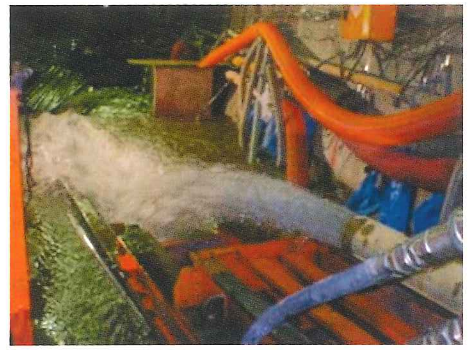


Photo 2 Water ingress

3) Treatment of inflammable gas

Existence of inflammable gas was investigated by advanced boring and the gas concentration was measured at the face, and gas was diluted by a large explosion-proof ventilating system.

3. Results of the tunneling

Of the present tunnel spanning about 22 km, the swelling ground where the convergence exceeded 10 cm spanned about 10 km. In the zone over about 4 km that produced especially large deformations, the multiple support system was used. As a result, the tunnel advance rate increased about 50% with costs reduced by about 15%, compared with the traditional re-cutting practice.

In the unconsolidated ground about 10 km long with high-pressure aquifer, and in the ground comprising inflammable gas about 14 km long, the techniques mentioned above were effectively utilized to achieve stable excavation.

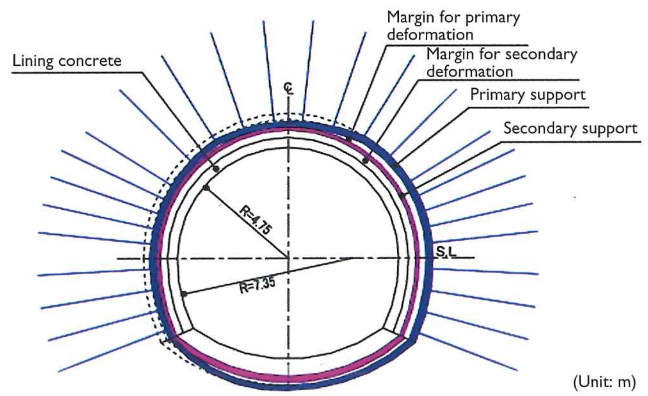


Fig. 2 Multiple support method

Center Diaphragm Method for Constructing a Large-Section Railway Station Tunnel
- Aobayama Tunnel on the Tozai Line of the Sendai-City Rapid Railway -

Akira HONDO
Chief of Sendai Construction Site Office
Tokyo Regional Bureau
Japan Railway Construction, Transport and Technology Agency

1. Overview of the Tozai line and large-section station cavern

The Tozai Line of the Sendai-City Rapid Railway is about 14.4 km long with thirteen stations, under construction for alleviating traffic congestion and facilitating access to the central district of Sendai that is a hub city in Tohoku district. This line is the second subway line in Sendai City, now under construction planned to be opened for service in 2015. The Aobayama station, the second station from the west starting station, is constructed deep underground, about 33 m. To curb construction cost, the open cut length is minimized to 55 m. As a consequence, the NATM zone (84 m long), accommodating the station facilities, adjacent to the open cut zone has a large cut section of 164 m^2.

The overburden of the large-section station zone is 22 m to 25 m. The geology in this zone is soft rock with an N-value (SPT blow count) of 50 or more.

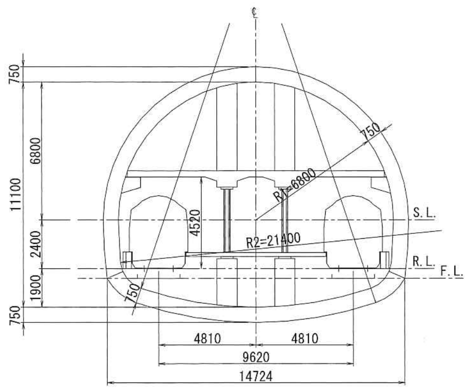


Fig. 1 Cross section of the large-section station tunnel

2. Construction plan of the large section station tunnel

When selecting a construction method, three methods were compared: side drift, center diaphragm (CD) and 3-stage bench method. As a result of the comparative study, CD method was selected because of its excellence in ease of construction and safety. The cutting sequence is as follows: the upper half of the advancing tunnel (left of the section) is cut to the arrival point, and the upper half of the succeeding tunnel is excavated in the same way, then the lower half is cut in two portions left and right. Subsequently, after in-tunnel displacements are confirmed to have converged, the central diaphragm is removed. A twin header machine was used, which is suitable for geological and ease-of-work reasons. The central diaphragm supports were removed with an elevated work platform vehicle and a large breaker.

3. Tunneling results

The excavation of the large section station tunnel started in the beginning of July 2009, with the cutting of the upper half of the advancing tunnel. When the excavation of the upper half on both sides was completed, the crown settlement was around 10 mm. Since this was smaller than initially predicted, in order to improve cost effectiveness and work efficiency in the succeeding half zone over about 50 m, the tunneling method was changed, that is, it was decided to install diaphragm supports only in the upper half, and to excavate the lower half without partition. The cutting of the upper and lower halves of the large section station tunnel was completed safely in mid-October.

Photo 1 View of the large-section station tunnel under construction

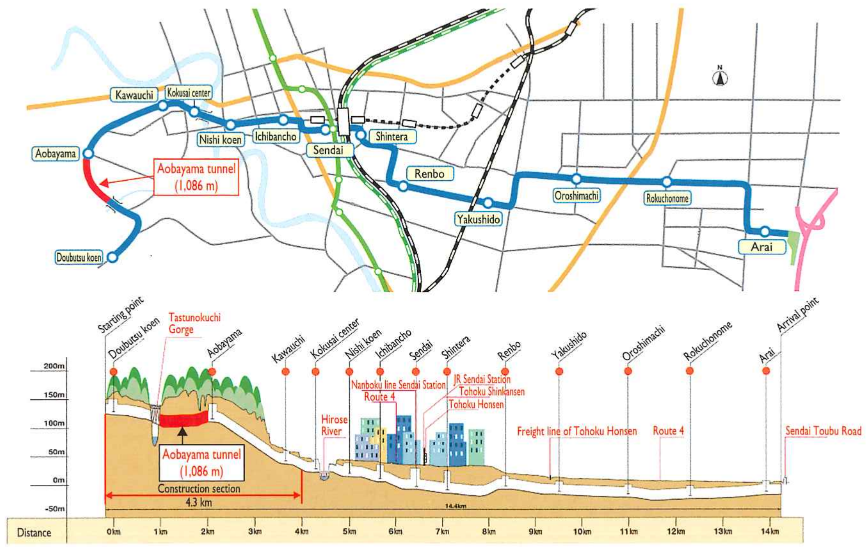


Fig. 2 Overview of the railway line

Seismic Retrofit of Tunnels by Means of Large Machine Train Sets

Keiji ONO
Vice Manager
Construction Department
East Japan Railway Company

1. Background of the seismic retrofit of tunnels

The Niigata-ken Chuetsu Earthquake in 2004 caused extensive damage such as collapse of the lining of the tunnels near the epicenter fault. In the wake of the disaster, East Japan Railway Company has been implementing seismic retrofit of the railway tunnels, for the purpose of preventing the tunnel lining from collapsing and other damage during an earthquake and ensuring safety of the railway traffic.

2. Overview of the project

The seismic retrofit is composed of three techniques: reinforcement of the lining from inside, backfill grouting and rock-bolting (Fig. 1), as described below.

1) Reinforcement of the lining from inside: This is the work to reinforce from inside the linings that are thinner than the design thickness or are damaged, in order to improve integrity of the lining.
2) Backfill grouting: When a cavity exists on the back of the tunnel, the lining tends to be damaged due to localized stress concentration. By filling the lining back cavity with grout, earth pressures acting on the lining are dispersed and made uniform.
3) Rock-bolting: If an extensive adverse alteration exists in the tunnel lining, there is fear the lining might fall in a large block during an earthquake. As a solution, the lining and ground are fused by means of rock-bolts.

The retrofit work is performed during a short period of about 2 hours at night when the railway is not in service. The work must necessarily be executed efficiently in a limited period. New machines for this project have been specifically designed and built (Fig. 2). The machine train set for the liner reinforcement from inside is composed of several scaffold wagons with specific lifts that are coupled with each other, and motor cars with work lifts connected at the top and the tail. The machine train set for rock-bolting is constituted of wagons with drill for rock-bolting (Photo 1), wagons carrying rock-bolt anchor grouting equipment, wagons with a slide basket, and a motor car with a work bench lift on each end of the train.

For the seismic retrofit project, four sets of each machine train were manufactured, and the work has been underway since 2008.

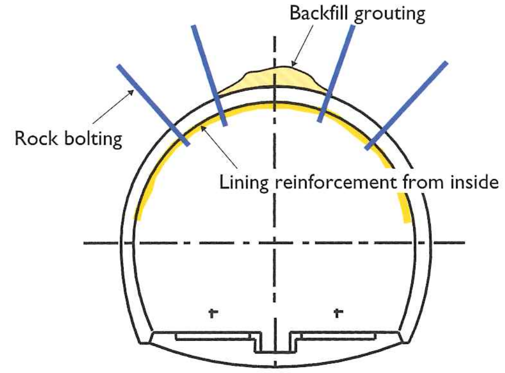


Fig. 1 Schematic diagram of the seismic retrofit

Photo 1 Rock bolting

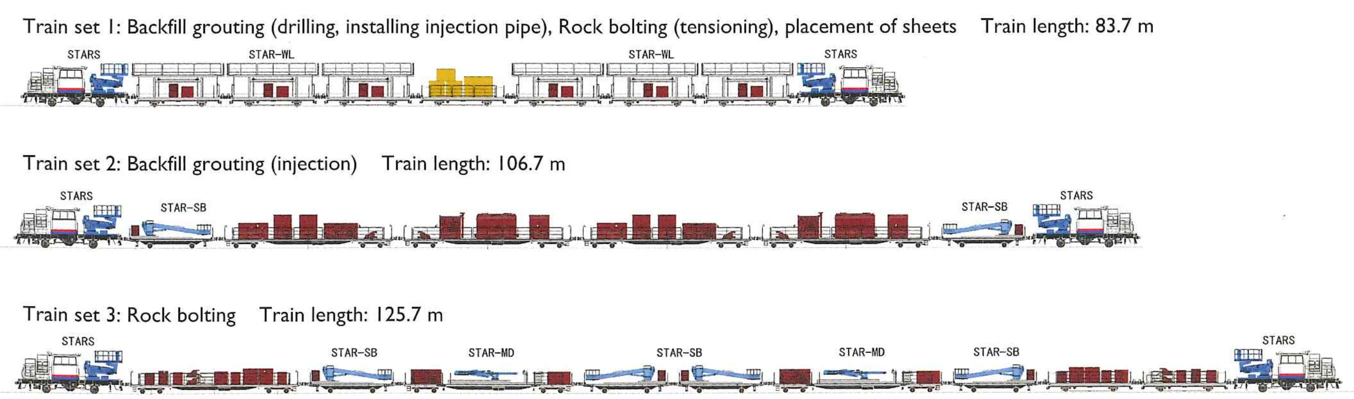


Fig. 2 Machine train sets for seismic retrofit

Construction of an Underpass Using a New Structure Combining Two Non-Open Cut Methods

Hiroshi FUKUSHIMA
Chief
Tohoku Construction Office
East Japan Railway Company

1. Overview of the project

This project constructs a road crossing beneath the Shinkansen and conventional railway lines (underpass below railway tracks). At the crossing below the conventional line, a box structure is built by the non-open cut method (Fig. 1). The road cross section is composed of one-story, four spans, accommodating two lanes on each side, with walkways on both sides (Fig. 2, Photo 1).

The project features the use of a new structure combining two different non-open cut methods, the JES for the car lanes and the COMPASS for the walkways (Fig. 2). The upper slab elements were pulled to be placed at a high rate, one element per day during a limited time between passing trains during the night.

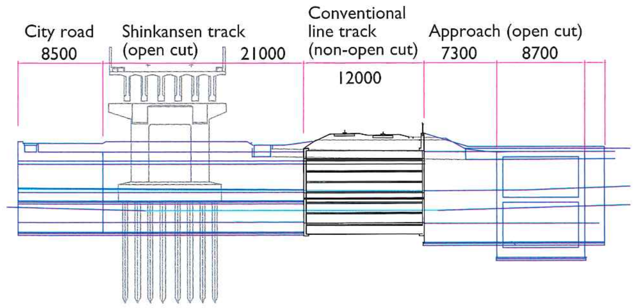


Fig. 1 Side view of the road

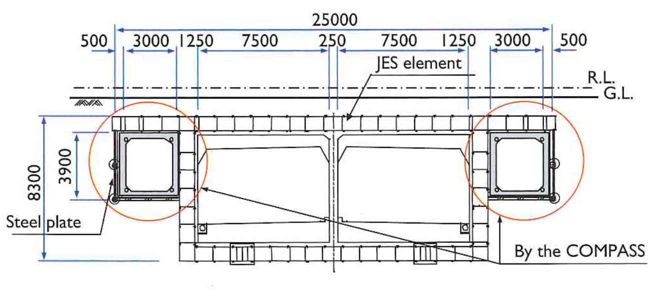


Fig. 2 Cross section of the road

2. Overview of the HEP&JES and COMPASS methods

The JES method is a non-open cut technique that inserts steel elements (JES elements) provided with JES joints that transmit forces in the ground, to construct an underground structure using the placed elements.

The COMPASS method is another non-open cut technique to make a small-section crossing structure with an inner cavity of approximately 3.5 m x 3.0 m. While cutting the ground with a wire saw specifically designed for this purpose, protection steel plates are inserted on the four sides of the circumference of the planned structure, then the inside of the four steel plates is excavated to form the structure (Fig. 3).

3. Features of the construction

(1) New structure combining two non-open cut methods

The conventional construction method of structures crossing below railway tracks is to create rectangular sections of walkways and car lanes at the same height, and backfill the walkway section to shorten the approach to the walkway. The present project combined the JES and COMPASS to construct a reversed convex section, which reduced the construction cost and impact on the Shinkansen structure during excavation.

(2) Rapid placement of the upper slab elements

Placement of upper slab elements with a shallow overburden must be performed during the night when the railway is not in service, posing a problem of a prolonged work period. In the present project, reviewing the transportation capacity of the ribbon screw of the cutting machine, the mechanical equipment was improved and measures against adverse alteration of the tracks were taken. All these contributed to high-speed placement of the elements, that is, 12 m pulling of one element (1.0 m wide x 0.85 m high) during about four hours when the trains were not in operation. The element pulling speed was 70 to 100 mm/min (90 mm/min on the average). The work period was shortened without exerting impact on the tracks.

Photo 1 View of the construction site

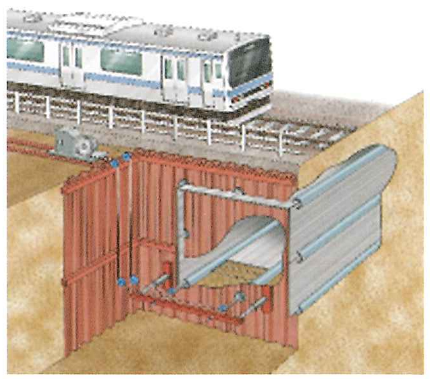


Fig.3 Overview of the COMPASS
[During construction]

The Yokohama Municipal Subway "Green Line"

Jun MITSUO
Group Leader, Geotechnical and Foundation Group
Civil Technology Department, Civil Construction Division
Tokyu Construction Co., Ltd.

1. Introduction

The Yokohama City-owned subway, "Green Line" is a route of approximately 13 km starting at Hiyoshi Station on the Tokyu Toyoko Line in Kohoku Ward and ending at JR Nakayama Station in Midori Ward of Yokohama City. The starting section, which is located below Hiyoshi Station, extends under the campus of Keio University (with overburden of 10 m), and will be constructed as a huge structure of large sections (30 m long) whose excavation sectional areas total 256 m^2. This project is larger than any previous tunnel project. To minimize the effect on the surface area, the project used a non-open cut method.

2. Tunneling

The geology of the tunneling route consists of an alternation of strata, mainly sandy soil and mudstone, and in the crown of the tunnel, there was an aquifer depository terrace 1 m deep, and on top of it, there was an accumulation of loam formation with 5 to 6 in N-value. When tunneling under these geological conditions, it was absolutely necessary to take precautions against water springs and collapse of the crown. Considering the magnitude of the excavation sectional area of 256 m^2, stabilization of the cutting face and achieving the desired bearing capacity of the soil were challenging when excavating the upper half of the face.

Top heading with advancing of the side drifts was used to achieve the desired bearing power of the soil. Various auxiliary methods were used, including the pipe roof method (1016 mm in diameter and 38.5 m in length) for prevention of springs, crown collapsing and ground surface subsiding. Ultra-long face bolts (32.5 m), longer than conventional long face bolts (12.5 m), were placed to stabilize the cutting face.

The pipe roof was constructed with a pipe-jacking method by sealing the outer circumference of the crest of the tunnel, and in order to increase the stiffness of the pipe roof, mortar was filled into the bores of the steel pipes which were already placed in-situ.

For the placement of ultra-long face bolts, bores were drilled while stabilizing the bored wall with the casing pipes (135 mm in diameter) and fiber bolts (76 mm in diameter) that were inserted in the casing pipes, and after removing the casing, mortar was injected into the voids that had formed.

Through this project, it can be confirmed that the use of ultra-long face bolts is more beneficial than conventional long face bolts, in stabilizing the face, and with this process, the construction could be completed safely. Another significant fact is that the placement of face bolts for the tunneling segment of a large cross section, starting from the shaft, could be completed in a single cycle, and therefore, the construction cycle was able to be shortened.

3. Results of measurements

Measurements for a standard procedure normally include convergence and stresses on steel supports, but in this project, subsidence of the pipe roof was also measured. Considering that the pipe roof's settlement would be measured for a long period of time, from boring start to the construction of the structure, the project adopted a settlement measuring method relying upon the use of optical fibers that were highly weather resistant and free from electric noises.

The measurement results show that the convergence and the stress on steel supports were within the predicted range. The maximum settlement of the ground surface was approximately 30 mm and that of the pipe roof about 40 mm at the final stage. The project was successfully completed without adverse effects on the surroundings.

Photo 1 Upper half excavation

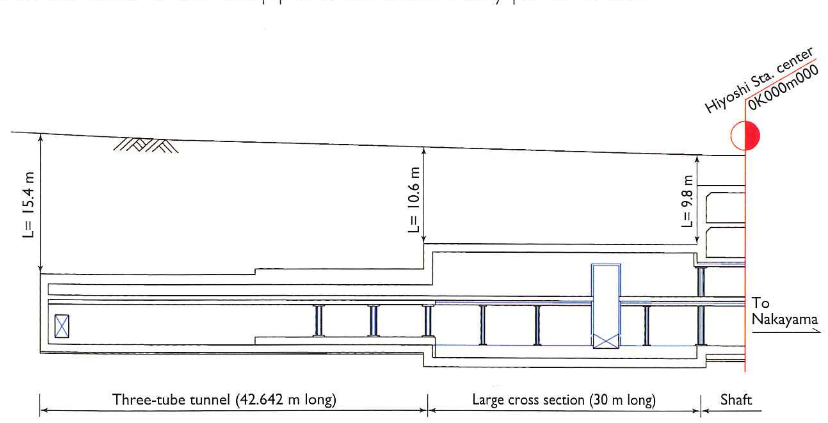


Fig. 1 Longitudinal section

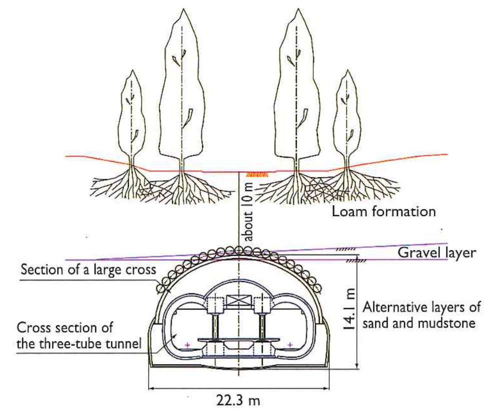


Fig. 2 Cross section

Rectangular-Section Shield Tunneling Using the Apollo Cutter
- Railway Tunnel between Shibuya and Daikanyama on the Tokyu Toyoko Line -

Takaaki KAKUTA
Assistant Manager
Tokyu Corporation

1. Introduction

Tokyu Corporation is proceeding with a huge improvement project spanning about 1.5 km from Shibuya metro station to Daikanyama station of the Tokyu Toyoko Line. Of the project length, a section 508 m is driven by a shield machine. This shield tunneling is performed just below an existing railway viaduct, arriving at a shaft immediately beneath the viaduct. The geology of the site is composed of Neogene cohesive soil stratum, and Quaternary gravel and sand strata and cohesive soil. A viaduct protection was placed before excavation just below the viaduct. Since the overburden is shallow, the "Apollo" cutter was selected, which has a low-height double rectangular section capable of boring a special sectional geometry.

2. Double rectangular segments

This project uses segments of reinforced concrete and steel framed reinforced concrete 0.4 m thick and 1.1 m wide each. The tunnel 10.3 m wide and 7.1 m high is divided into ten parts per ring. The section is composed of a couple of rectangular sections with a composite steel rectangular column at the center.

3. Apollo cutter

The tunneling is being performed with a high-density slurry shield. The overburden ranges from 4.5 m to 15.4 m, the minimum curvature radius is 160 m, and the maximum gradient is 35 ‰. The shield machine with the new technology, Apollo cutter, is an articulated type. A rotating cutter head is mounted, via an oscillating frame, on the main drum making orbital revolutions. While the cutter head and main drum rotate, and the oscillating frame swivels, the machine bores the planned section. This system is capable of cutting sections of various geometries and is also applicable to hard ground.

4. Viaduct protection

In the excavation section just below the existing railway viaduct, three types of viaduct protection shown in Fig. 1 were adopted according to the ground condition as follows:

1) section of hard ground where the shield passes under deep overburden (Section 1),

2) section with a thin layer of Neogene cohesive soil or with gravel layer (Section 2),

3) section near the arrival shaft where the overburden is shallow (Section 3).

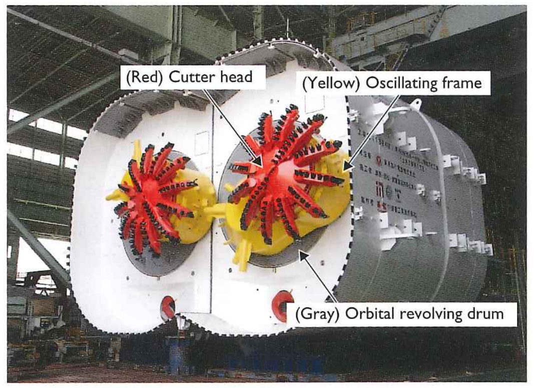


Photo 1 Shield machine

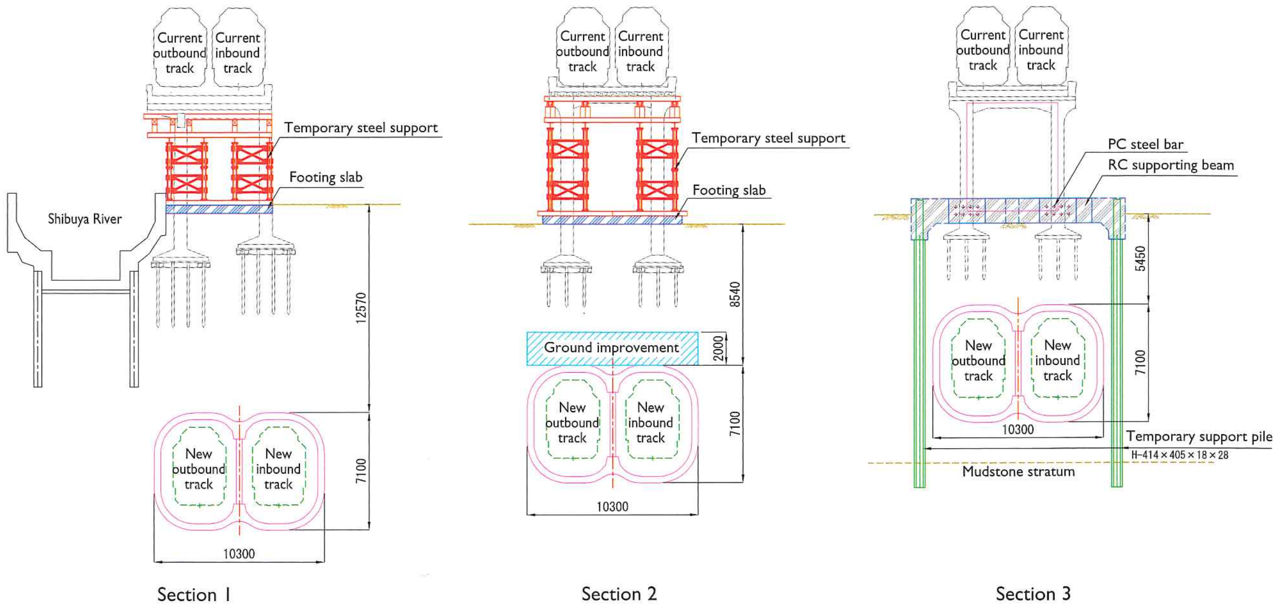


Fig. 1 Sections of the viaduct protection

Twin Tunneling Below Railway Lines in Service by Making U Turns with a Shield Machine
- Project of Grade Separated Crossing near Chofu Station -

Tadayuki IWAMURA
General Manager
Chofu Construction Office, Facilities Engineering Department
Railway Management Headquarters, Keio Corporation

1. Overview of the project

The Tokyo metropolitan government, Chofu city government and Keio Corporation have been working on a grade separated crossing project in the vicinity of Chofu station since September 2004. The purpose of this project is to prevent traffic accidents, alleviate chronic traffic jams, remove inconvenient division of the district by the railway tracks, and improve the environment in the surrounding district . This project will move two lines in service underground, to eliminate 18 crossings and grade separation at eight locations on urban roads. The depressed section for the station and entrance to the underground space is excavated by open cut, and the tunnel between stations is bored by a shield machine.

2. Features of the shield tunneling

(1) Single U turn section

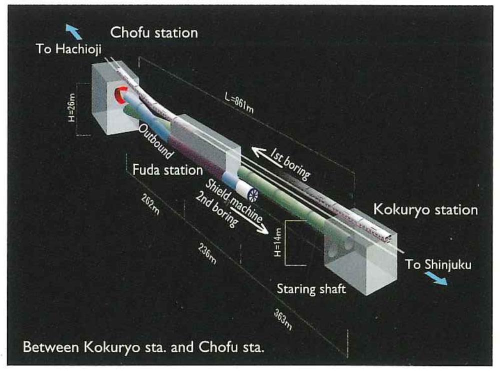
A single U turn of a high-density slurry shield machine makes two bores 1,722 m in total. This section features the following:

1) The tunnel is bored just below the railway lines in service, in the longitudinal direction (track-wise) continuously with a small overburden (4.7 m at minimum).

2) The geology of the site is mainly composed of gravel stratum, containing little binder, with the maximum gravel diameter of 300 mm.

3) The groundwater level is unsaturated in the shield tunneling section, varying seasonally.

4) The minimum distance between the parallel bores is 400 mm.



5) In the shaft at Chofu station just below the railway line in service, the shield machine of about 3 MN is rotated and lifted.

(2) Three U turns section

Three U turns with a high-density slurry shield machine make four bores 1,606 m in total. This section features the following:

1) The tunnel is excavated just below the railway lines in service, in the longitudinal direction (track-wise) continuously with a small overburden (4.3 m at minimum).

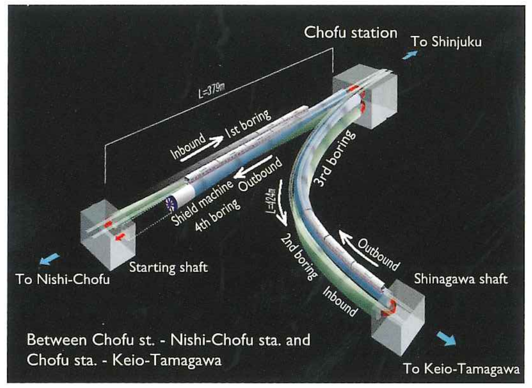
2) The minimum distance between the parallel bores is 424 mm.

3) Steeply curved alignment, with a radius as small as 160 m.

4) In the Chofu station shaft just below the railway line in service, the shield machine is pulled out and rotated twice, and in the Shinagawa shaft, the shield machine is pulled out and rotated once.

5) The site is in the gravel stratum, with the maximum gravel diameter of 300 mm.

6) Composite segments made of steel and reinforced concrete are used at the steep curve section of the 2nd boring, to provide the structure with a greater rigidity, more immune to impact of the 3rd boring in the proximity.



3. Displacements of the railway tracks

The primary control value was set at 14 mm, the secondary control value 20 mm and the limit 30 mm, under around-the-clock track maintenance and automatic measurement and monitoring. The measured displacements were generally within 5 mm.

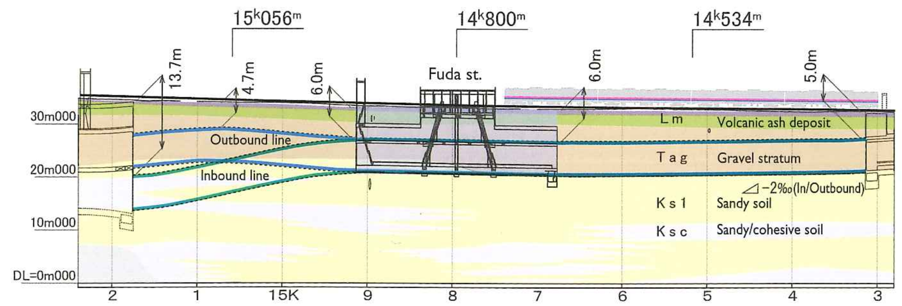


Fig. 1 Longitudinal section

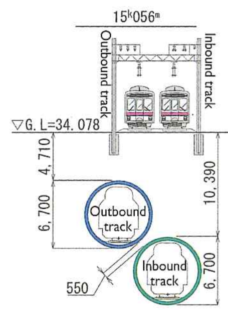


Fig. 2 Cross section

Early Section Closure of High Resistance Support Structures, to cope with Squeezing Earth Pressures - San-en Tunnel, San-en Nanshin Expressway -

Akihiro MORITANI
Director, Hamamatsu Office of River and National Highway
Chubu Regional Development Bureau
Ministry of Land, Infrastructure, Transport and Tourism

1. Introduction

The San-en Tunnel is a road tunnel 4,525 m passing through huge serpentine bedrock spanning about 350 m and a fault, the largest in Japan, extending 76 m (Fig. 1). The overburden at the construction site is 70 to 140 m, and the geology is clayey and foliated serpentine, fragile and squeezing, the ground competence factor being 0.7 to 1.2. Therefore, there was a fear of excessive tunnel displacement, face collapse, adverse alteration and failure of the tunnel support structure during tunneling.

2. Design and construction plan

In the design, the support resistance was calculated on the basis of the thick-wall theory, which is necessary to resist squeezing earth pressures. Referring to the calculated values, a highly resistant tunnel support structure was designed, mainly composed of high-strength shotcrete of 36 N/mm^2 in compressive strength (Fig. 2). The section closure radius R4 was set at 8.8 m, taking the ratio R4/R1 = 1.44 with upper half support radius R1 = 6.1 m, to form a quasi-circular tunnel section.

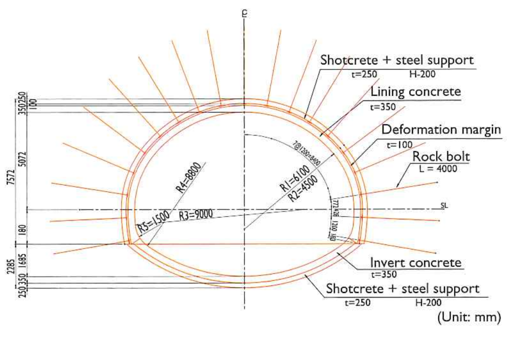


Fig. 2 Support structure

The principal auxiliary method selected was spraying on the face to ensure safe work. To maintain stability of the excavated surfaces until the support is installed, and achieve the design quality and construction integrity, forepoling with grouting and AGF forepiling (long steel tube forepiling with grouting) were used, depending upon geological properties and scale of distribution of geological formations. The construction was planned with a section closure unit of 3 m, and full-face cutting with auxiliary bench. Upper/lower half cutting and section closure were alternately repeated in the range 7 to 10 m from the upper half face (Fig. 3).

3. Tunneling results

In the tunneling in the serpentinite, the crown settlement was within 10 mm and convergence within 25 mm. In the median tectonic line main fault, due to significant impact of non-uniformity of bedrock properties, the maximum crown settlement was 38 mm and the convergence was 72 mm. However, these deformations converged within the deformation margin of 100 mm (Fig. 4). The largest axial stress induced in the shotcrete was 12 N/mm^2 that was smaller than the compressive strength, validating mechanical stability of the tunnel. Load acting on the high-strength support structure was estimated to be equivalent to overburden of 30 m. The design and construction method of this project was confirmed to enable safe and sure tunneling, applicable to squeezing ground.

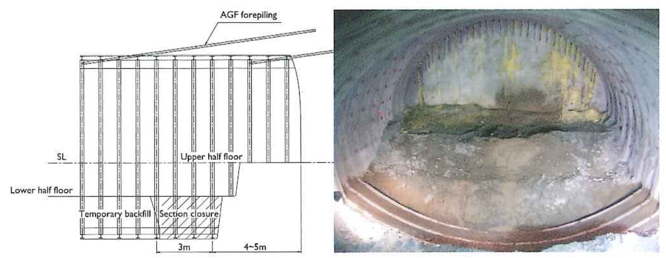


Fig. 3 Early section closure with mini bench

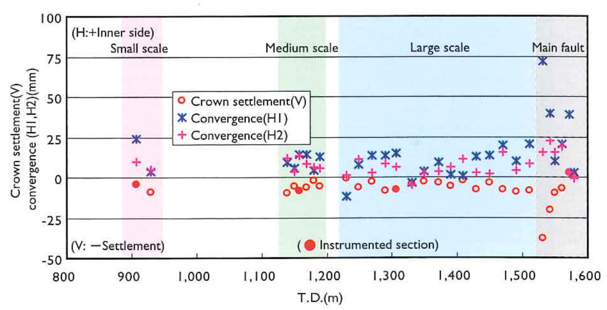


Fig. 4 Displacement of tunnel wall (Serpentine and median tectonic line main fault)

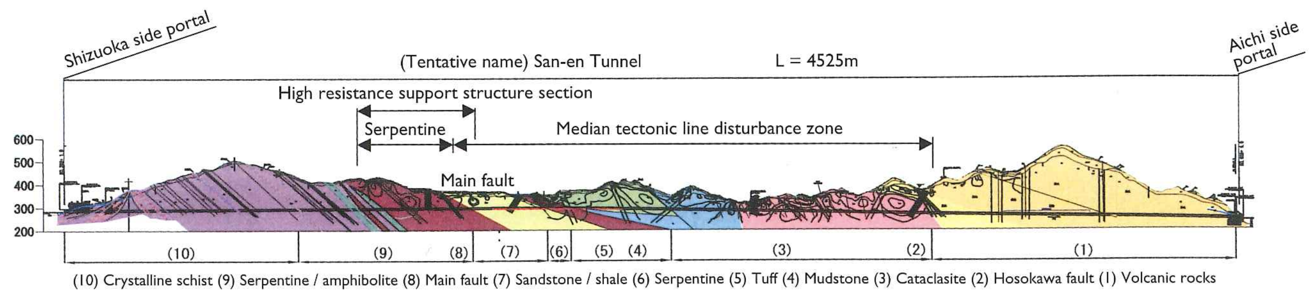


Fig. 1 Longitudinal geological profile

Construction of an Underpass at a Congested Intersection by the Large-Section Divided Shield Tunneling (Harmonica Method) - Improvement of the Harajuku Intersection -

Takeo SAWA
Chief of Fujisawa Office, Yokohama National Highway Work Office
Kanto Regional Development Bureau
Ministry of Land, Infrastructure, Transport and Tourism

1. Overview of the project

The purpose of the Harajuku intersection improvement project under way in Yokohama is to restore smooth traffic flow, by grade separation of Route 1 to separate the through lane on this national highway from the entry/departure of the Kanjo No. 4 route.

The project length is 828 m, with an underground section of 420 m. The stretch of 186 m near the intersection is in a box culvert structure. Of this site, the section of 73 m just below the intersection was constructed by the "harmonica method," a non-open cut technique.

The harmonica method divides the rectangular large-section tunnel into multiple tubes which are excavated by a small shield machine, then unites the small-section tubes into a single bore, where a structure is built. The shape of the portal when excavation of the divided sections is complete, is like reed chambers of harmonica. This is the reason why this technique was dubbed "harmonica method."

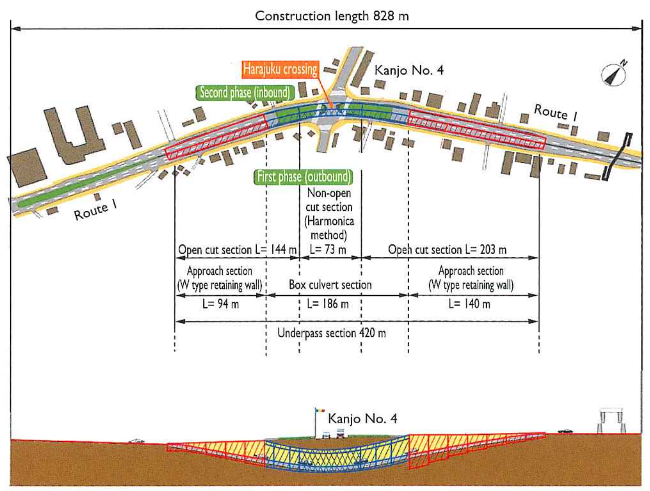


Fig. 1 Plan of the project

Fig. 2 Overview of the harmonica method

2. Construction of an underpass

The underpass for four lanes (two for each traffic direction) is divided into 10 sections to be constructed by the harmonica method. Six tubes for two lanes for a single traffic direction were constructed first, opened to provisional service in April 2009, mitigating traffic congestion. Opening to full service is planned in December 2010.

The harmonica method section is 73 m in cutting length with the minimum overburden of 1.7 m. The road alignment is 3D curve with a plane curve of 320 m in radius and a vertical curve of 1,000 m in radius. The structure size is 7.250 m high × 18.600 m wide. For excavating this structure, tubes 3.980 m high and 3.830 m wide were arranged vertically in two stages and horizontally in 5 rows, ten tubes in total (six tubes excavated in the first phase, and four in the second phase. Fig. 3). The length of one ring was 1.25 m. The span of 73 m was divided into 58 rings.

The work is done in the order B1→ B2→ B3→ U1→ B2→ U3.

In the six tubes reinforcing bars and formworks are assembled and concrete is placed to build the large-section tunnel. After the concrete is cured, the inner steel shell (main beams, vertical ribs and skin plates) is cut and removed, then finishing work is performed.

In the second phase, as in the first phase, the work is performed with the steps of B4→ B5→ U4→ U5, then the structure is connected with the tubes built in the first phase to complete the box underpass accommodating four lanes.

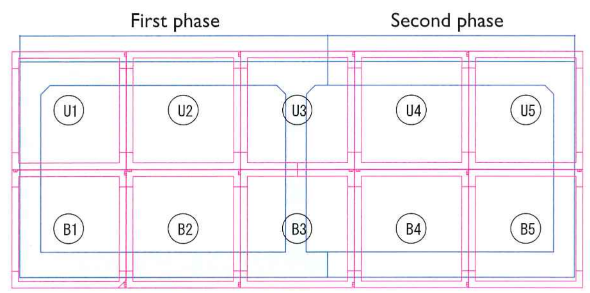


Fig. 3 Divisions for the harmonica method and construction sequence
B1→B2→B3→U1→U2→U3 : First phase
B4→B5→U4→U5 : Second phase

Photo 1 Breakthrough of the shield machine: B2

Overview of Renovation of the Kanmon Tunnel on Route 2

Yasuo FUKUNAGA
Improvement Group Leader
Maintenance and Service Department
Kyushu Branch, West Nippon Expressway Co., Ltd.

1. Project outline

The Kanmon Tunnel is an undersea roadway tunnel that crosses the Kanmon Straits. It has a total length of 3,461 m and is composed of two levels: a two-lane roadway and a pedestrian walkway (Fig. 1). Since its opening in March 1958, over the past 50 years the tunnel has played an essential role as a major artery for transportation of goods and an important community road for bicycle commuters, etc.

The traffic volume through the tunnel has increased nearly seventeen-fold from approx. 2,000 cars per day at the time of its opening to approx. 35,000 cars a day today. Taking into consideration the fact the tunnel is an undersea structure, and in view of the increased traffic volume and the growth in the size of vehicles, as well as the aging of the main tunnel structure and the ancillary structures, it has become necessary to efficiently maintain and manage the tunnel facilities. In 1973 the Kanmonkyo Bridge across the Kanmon Straits was completed at a location close to the tunnel, and it became possible to use the bridge as an alternate route and periodically close the tunnel to traffic in order to perform required repairs. Since 1973, once every ten years the tunnel has been closed for traffic and large-scale repair work has been carried out.

2. Technical characteristics

In the repair work in 2008, the tunnel was closed to traffic for a period of 60 days, and for the first time since its opening, the ceiling boards for the ventilation units installed in the upper part of the tunnel were replaced because of degradation of the concrete parts and damaged metal fittings for hanging (Fig. 2). The plan for the 2009 and 2010 repair works includes replacement of the floor slabs in the 780-meter undersea section of the tunnel (Fig. 3). In 2009, construction was completed for a 380-meter long section. In order to improve the strength of the floor slabs in response to the increased vehicle volume and size, to enhance their resistance to sea water, and make work easier (shorter construction periods), various factors were thoroughly examined including the economic efficiency of construction, and it was decided to use FRP (Fiber Reinforced Plastic) floor slabs in the new construction (Fig. 4). Furthermore, by adopting anti-corrosion reinforcing bars and fine particle blast-furnace slag used for making exceptionally dense concrete, we managed to improve the durability against seawater. As a result, the repair work was successfully completed in a relatively short period of approx. 100 days.

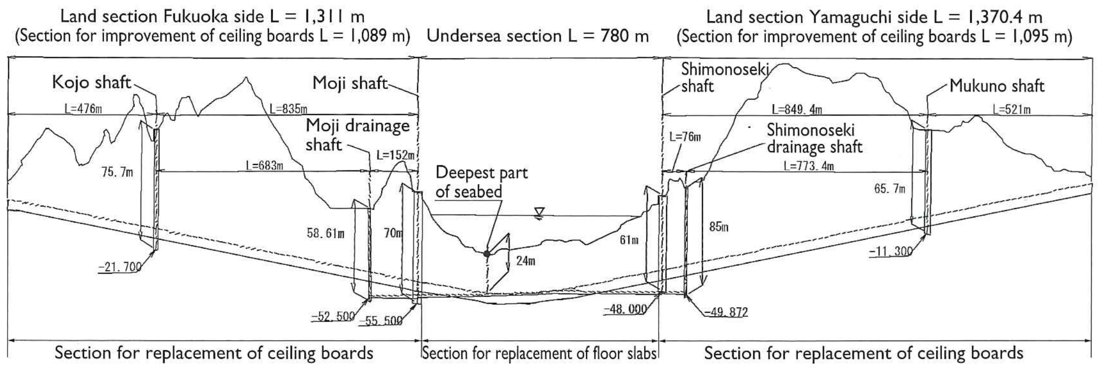


Fig. 1 Longitudinal section of the Kanmon Tunnel

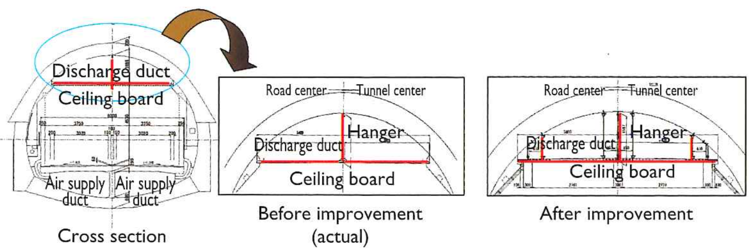


Fig. 2 Ceiling board replacement

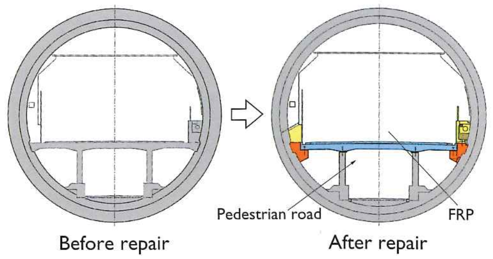


Fig. 3 Replacement of undersea section floor slabs

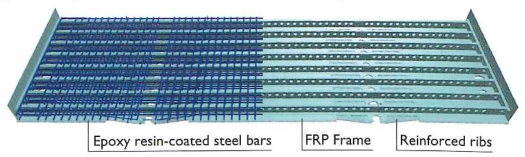


Fig. 4 FRP floor slabs

Construction of an Extremely Large-Section Twin-Tube Tunnel Passing Directly Below an Important Structure - Imazato Tunnel, Shin-Tomei Expressway -

Osamu MIYOI
Susono Construction Chief
Numazu Construction Office, Tokyo Branch
Central Nippon Expressway Company Limited

1. Overview of the project

The Imazato tunnel is a mountain tunnel 777 m long, located in Susono City between the Gotenba Junction and Nagaizumi-Numazu Interchange of the Shin-Tomei Expressway, passing through ground composed mainly of eruptive lava of Mt. Fuji. The tunnel is composed of a non-open cut section 385 m long and an open cut section 392 m.

The excavation section as shown in Fig. 1 is about 206 m^2 that is nearly 2.5 times as large as the two-lane tunnel of the existing Tomei Expressway. The overburden is shallow, about 10 m. There are private research facilities and Susono City roads directly above the tunnel route. Twin-tube tunnels have been conventionally designed with center-to-center distance between the tubes approximately three times the excavation width, in order to prevent unfavorable interference between tubes. The present project was however designed with an almost halved distance, that is, 1.5 times the excavation width (net separation 4 to 6 m) as shown in Photo 1. This is a very rare case.

The geology of the site is a discontinuous alternate layer of very hard basalt and unstable autobrecciated lava.

Under these adverse conditions, the key goals were to maintain mechanical stability of the extremely large-section twin-tube tunnel and integrity of the private research facilities and existing important structures directly above the tunnel.

2. Technological features

The tunnel section was designed with a single-centered circle upper half that is mechanically favorable. In order to prevent autobrecciated lava from excessively deforming due to its low strength, ground stability was maintained by making the strength of the complex geological formation uniform, through improvement of the ground by means of advance grouting from the surface including the portion below the buildings (Fig. 2).

For ground improvement, ultra-fine particle cement and cement bentonite were used. The ultra-fine particle cement penetrates well into minute interstices. The cement bentonite, though less penetrating, enables formation of the intended improved mass (deformation modulus more than 200 MPa, improved width 6 m). To improve ground effectively and surely, a ground evaluation system was used, which was composed of a drilling machine provided with various sensors, and test improvements were made in advance on the site to confirm the improved status.

To curb surface displacement and stabilize the face, the center diaphragm method was adopted (Photo 2). Monitoring around the clock the behavior of the ground, and checking the impact upon the research facilities above, the number of cutting divisions was changed. As a result, the work period was significantly shortened.


Photo 1 Tunnel portal

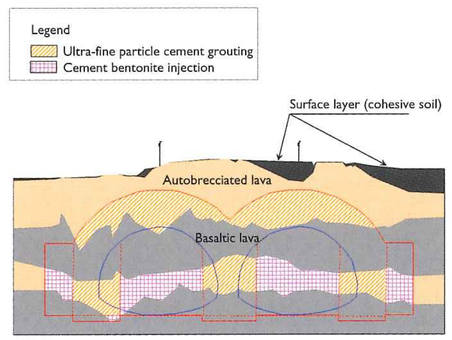


Fig. 2 Ground improvement range

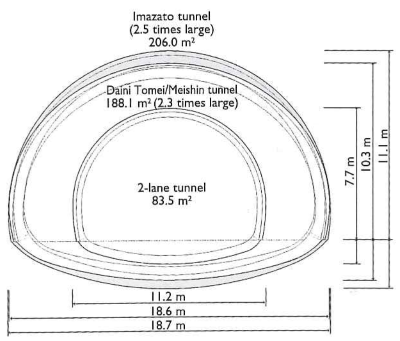


Fig. 1 Cross section

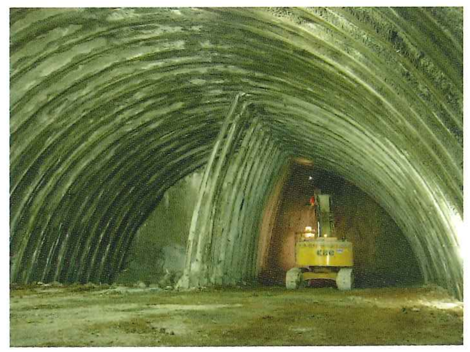


Photo 2 Excavation work

Breakthrough of a Tunnel Using TBM in Collapsing Ground with Huge Water Ingress - East Evacuation Tunnel of the Kuriko Tunnel on the Tohoku Chuo Expressway -

Kazuo MIYAZAWA
Kuriko Tunnel East Construction Section Manager
Koriyama Construction Office, Tohoku Branch
East Nippon Expressway Company Limited

1. Overview of the project

The Tohoku Chuo Expressway is about 270 km in length. The Kuriko Tunnel on this expressway is a long tunnel spanning 9 km. Once completed, it will be the third longest mountain tunnel in Japan. Prior to the construction of the main tunnel, an evacuation tunnel was bored for the double purpose of geological investigation and water drainage. The geology on the east side was predicted to be constituted of hard bedrock, which would not induce significant water ingress. Therefore, tunneling by TBM was selected, which enables rapid advance and is more economical than other methods. The following gives a description of the huge amount of water ingress and collapsing ground, not predicted in the phase of design and investigation, and countermeasures.

Photo 1 Main system of the TBM 4.5 m diam.

2. Water ingress and ground collapse

The total water ingress was estimated to be 0.2 to 0.5 tons/min based on the advance investigation. However, at 700 m from the portal, a sudden gush of water of 5 tons/min occurred, and afterwards, a great amount of water ingress took place twice. The water ingress totaled about 8.3 tons/min. Although the ground was initially estimated to be mainly composed of hard rock, the geology turned out to be composed of fissured granite in the first half of the tunneling, accompanied by water ingress and collapse in the fractured zone. In the middle and succeeding portions of the tunneling, tuff, sandstone and mudstone appeared, presenting a lower rock resistance and a smaller competence factor, inducing collapse in layers. Especially in the alternate zone of sandstone and mudstone, crown collapse 50 to 100 cm high repeatedly occurred, and the tunnel wall squeezed out.

Photo 2 Collapse

3. Measures against water ingress and collapse

By the use of the rock drill mounted on the TBM, advance boring was made to investigate the status ahead of the face, quantitatively evaluating and predicting the ground condition. When an adverse geological condition with water ingress was found, water drainage boring was implemented in advance. To prevent extensive collapse which would restrict the TBM, long steel tube forepiles with injection (AGF forepiling) were driven. In the zone where medium to small scale collapses happened repeatedly, without halting the TBM cutting, tunneling was advanced by employing lagging and halved-log spiling for which materials could be easily provided on the site and additional spraying of fiber mortar which was excellent in operability and performance. All these measures were effective for safe tunneling.

4. Breakthrough using TBM in the adverse geological condition

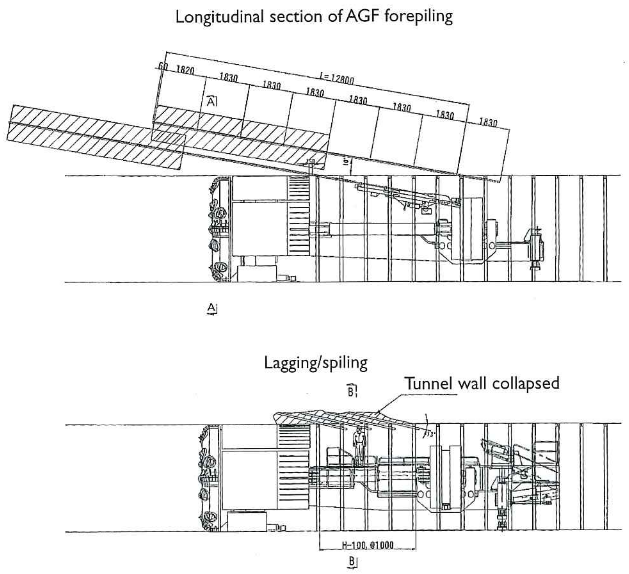


Fig. 1 Countermeasures against collapse

This project encountered a huge amount of sudden water inflow and collapsing ground. Nevertheless, the tunnel 5.5 km long was broken through, while not restricting the TBM at all. As performed in this project, advance boring for survey of the geology ahead of the face enables prediction of adverse geology, and measures to be taken in advance. This will expand the application scope of the TBM in adverse ground conditions. The present project advanced very rapidly despite unfavorable geological conditions compared with construction records of other projects using TBM, i.e., 31.5 m/day at maximum, 453 m/month at maximum and 240 m/month on the average.

Restoration of a Seriously Damaged Tunnel in Service - Sakazuki-yama Tunnel on the Yamagata Expressway -

Satoshi SAKUMA
Assistant Manager
Yamagata Management Office, Tohoku Branch
East Nippon Expressway Company Limited

1. Overview of the project

The Sakazuki-yama Tunnel (inbound lane tube 1,234 m long) on the Yamagata Expressway was opened to service on 20 July 1991. In the construction of this tunnel excavated in rhyolitic tuff, serious problems occurred such as convergence as large as 300 mm due to water ingress and expansive mineral. The outbound lane tube was opened in 2002, i.e., 11 years after the opening of the inbound service.

Almost 17 years after the opening, the road surface suddenly heaved, and the upheaval reached 250 mm the next day, and 380 mm after 11 days. The inbound lane tube was closed one week after the occurrence of the damage, and the adjacent outbound lane tubes were used for two-way traffic. The restoration plan was to remove damaged invert and construct an invert of higher load-carrying capacity as soon as possible. The upheaval of the invert was 950 mm at maximum. In the short period of three and a half months after the occurrence of the damage, the new invert, pavement and facilities were all constructed, and the tunnel was reopened to traffic on November 28. Consequently, the function of the expressway, an important infrastructure element, was restored before the heavy snow season (December).

Photo 1 Damaged invert

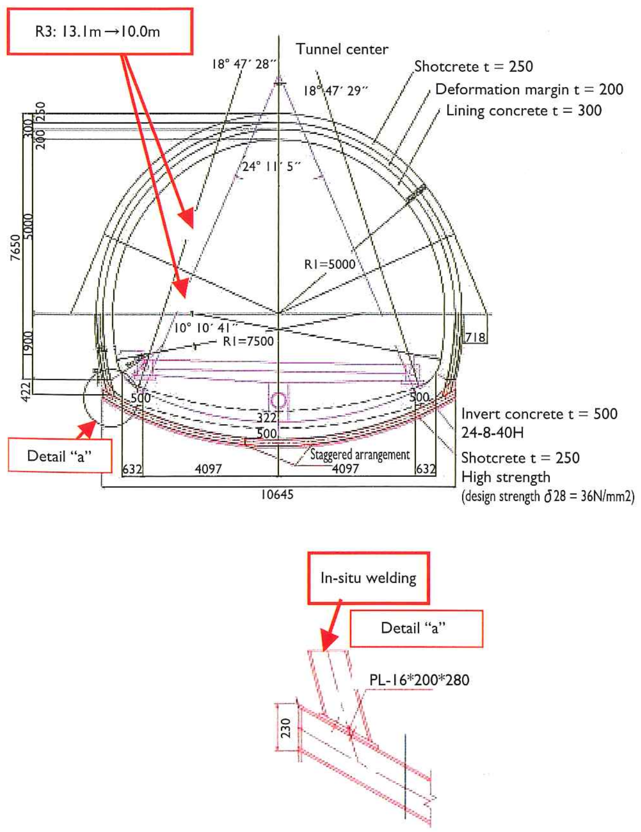


Fig. 1 Section of the restoration

2. Technological features

The cause of the serious damage was presumed as follows. The ground under the invert absorbed groundwater from the surroundings, expanded and lost strength, and heaving (expansive) pressures acted from below for a long span of time resulting in damage. The new invert (Fig. 1) is 10 m in radius (the damaged invert 13.1 m in radius), 24 N/mm^2 in strength and 500 mm thick. Its geometry is nearer to a true circle. The section was closed by the use of steel supports and shotcrete.

As shown in Fig. 2, the radial displacement rate was the highest at the time of the removal of the damaged invert. The radial displacement converging to the 111 mm more than 10 days after the new invert was placed. The stress in the lining measured immediately after the damage occurred was compressive, 12.4 N/mm^2, but it reduced by 3 N/mm^2 after the countermeasures were taken. An inspection after the restoration proved the integrity of the lining.

Such a large deformation and failure of the road surface and invert, which occurred a long time after completion of the tunnel, was an unprecedented event in Japan.

Photo 2 View of the restoration

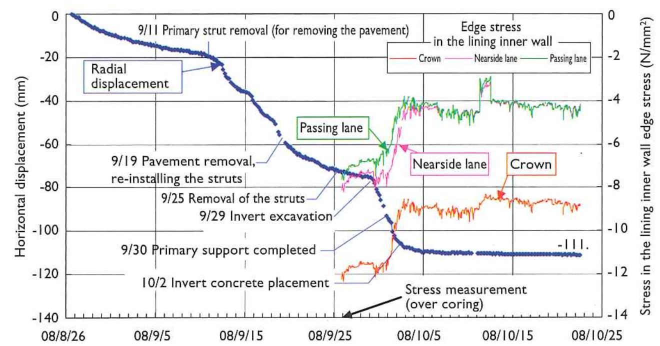


Fig. 2 Measurement results

Construction of a Large-Section Road Tunnel by the MMST (Multi Micro Shield Tunneling) Method

Tadashi YOSHIKAWA
Senior Engineer
Design Group, Kanagawa Construction Bureau
Metropolitan Expressway Co., Ltd.

1. Overview of the project

The Kawasaki Jukan Expressway is a motorway about 7.9 km long. Its key role is to form a wide-area road network to the cities in the vicinity and seaside district.

Below the road with heavy traffic, a tunnel of large rectangular section 540 m long was constructed utilizing the MMST method.

2. Summary of the MMST method

The construction site was located in an area where residences are crowded on both sides of the site for road construction. It was therefore necessary to exercise extreme caution to avoid adverse impact on the surroundings such as surface subsidence. The MMST is convenient for this aspect, especially when constructing a large-section tunnel with a shallow overburden in a limited space as in the case of this project.

The MMST method constructs a circumferential shell of large-section tunnel by joining small-rectangular-section shield bores. By changing the interval at joints between small rectangular section bores, it is possible to change the section size at the diverging and merging sections. Compared with the cut-and-cover method and conventional circular shield tunneling, the MMST features the following:

1) Use of small-rectangular-section shield enables non-open cut construction of a large-section tunnel with a shallow overburden.
2) The rectangular section produces smaller dead space than the circular section.
3) The section inside the circumferential shell is excavated by a general-purpose machine, producing less slurry.
4) By combining unit bores, it is possible to form the desired geometry and a large section. Therefore, this method is applicable to road alignments that have considerable variation.

In the Kawasaki Jukan Expressway project, with a site whose narrowest point is 29 m and the shallowest overburden is 4.8 m, a large-rectangular-section tunnel (18 m in inner height, 23 m wide) was constructed, involving section enlargement at branch and confluence, and a section varying from a double-deck configuration with two vertical layers to a parallel structure with two horizontal rows.

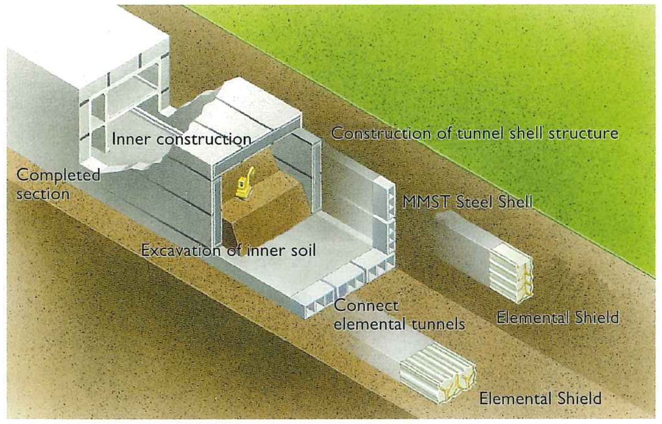


Fig. 1 Procedures of the MMST method

3. Inner construction

For rationalizing construction, the main structure of the car lane was composed of steel beams and columns, using semi-precast slabs. Semi-precast box culverts were used for making the main structure of the common duct and evacuation passage. Use of semi-precast slabs eliminated the need of forms and supports. Consequently, the lower layer of the double-layer configuration could be used as work passage during placement of the slabs. By utilizing precast members for the common duct and evacuation passage, it was possible to simultaneously perform re-bar arrangement on the slabs, concrete placement and erection of auxiliary equipment such as fire panels. The major structural members in the tunnel are fire proof structures, with fire panels mounted on the steel members and polypropylene fibers mixed into the slabs. For fire protection scheme, the RABT curve was used.

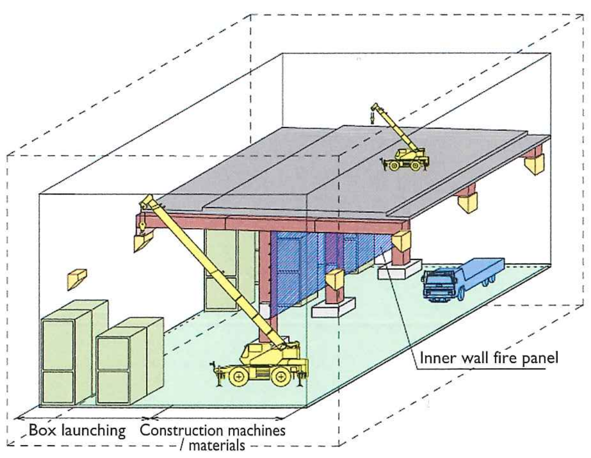


Fig. 2 Schematic of the inner construction

Photo 1 Tunnel shell structure

Photo 2 Inner construction

Twin-Tube Tunnel Constructed without Drift Just Below Residences, with Shallow Overburden - Shikina Tunnel on the Maji-kumoji Line -

Tsuguya ASATO
Chief Engineer, Nanbu Regional Public Works Office
Department of Civil Engineering and Construction
Okinawa Prefectural Government

1. Overview of the project

The Shikina Tunnel was planned as a part of the city planned road linking central Naha city and the suburbs. This tunnel was designed with a small overburden (40 m at maximum) immediately below residences. To minimize the restriction on the construction lot and impact on the ground surface, the distance between the tubes is very small, about 1 m, over the total span of the tunnel, 559 m (Fig. 1). The conventional method for constructing two tubes very close to each other would be to construct an advanced drift before the main tunneling, and place concrete pillars in the drift, then excavate the main tunnel. The present project does not construct a central drift and directly drives the main tunnel without drift.

The tunnel is located below the Shikina plateau. The geology is composed of a surface Ryuku limestone stratum, below which lies Shimaziri mudstone stratum. The tunnel was planned in the mudstone stratum (Fig. 2). The mud stone around the tunnel has an unconfined compressive strength of 1 to 2 MPa, comprising many latent fissures, featuring a very high tendency for slaking.

2. Technological features

The tunnel tubes were excavated in a single direction. The faces of both tubes were advanced simultaneously, maintaining a separation (about 80 m) between the faces so that the face of the second tube would pass after the impact of excavation of the first tube has been sufficiently attenuated. The full face excavation with mini bench was used, which enabled early section closure to ensure stability of ground and curb surface subsidence during cutting (Photo 1).

In construction of the twin-tube tunnel without drift, stress in the supports of the first tube varies also when the second tube passes by. Therefore, a high strength shotcrete (σck=36 N/mm^2) was used, which was more rigid than the support of the second tube. To guarantee effectiveness of early section closure, invert shotcrete (200 mm thick) was placed over the entire length of both tubes. In addition, in the zones with small overburden, invert struts (H-200) were installed. The entire section was closed, in the ordinary zone, at least 7 m and at most 9 m from the upper half face (Fig. 3).

At the exit portal, the important main piping that supplies water to Naha city was laid (11 m above the tunnel crown). To curb settlement during passing of the second tube, the invert was closed at a position closer to the face than in the ordinary zone, to further improve the effect of early closure (Photo 1). As a result, in the construction under severe conditions such as small overburden, the surface settlement finally converged to 26 mm, within the control target of 30 mm. In this way, the twin-tube tunnel was safely broken through without drift.

Photo 1 Early section closure

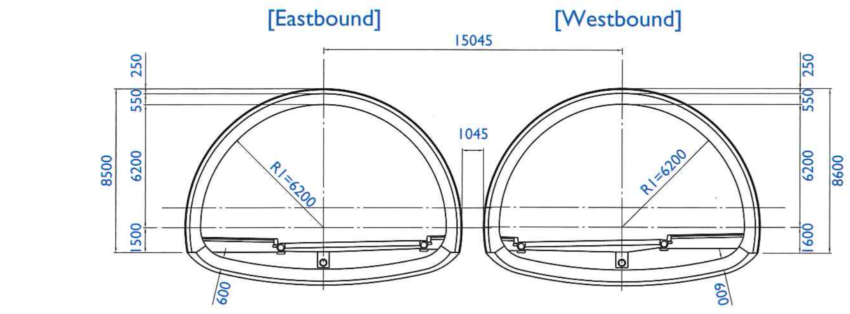


Fig. 1 Standard section

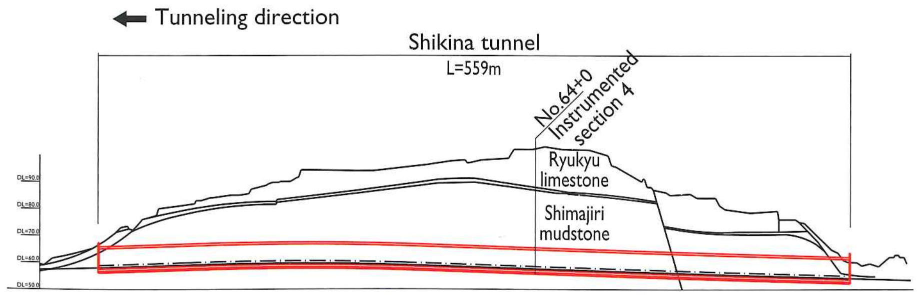


Fig. 2 Longitudinal geology

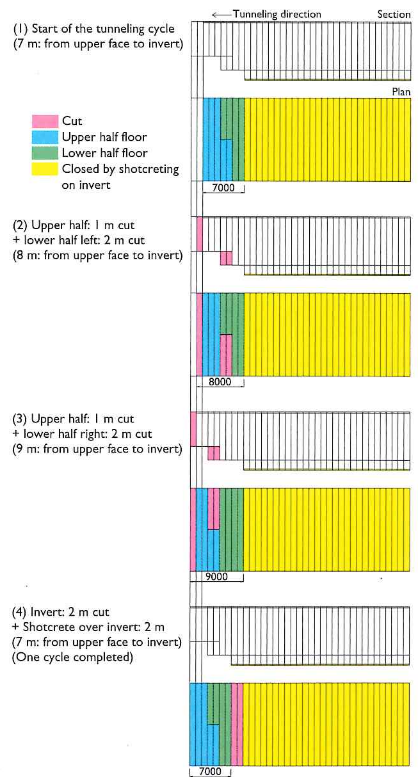
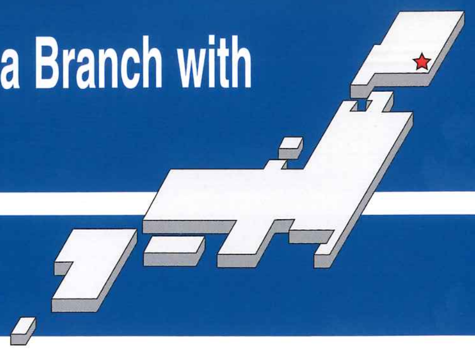


Fig.3 Construction sequence

Extension of an Existing Tunnel by Constructing a Branch with Minimum Traffic Control



Akira WATANABE

Director, Urakawa Road Office, Muroran Development and Construction Department, Hokkaido Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

1. Overview of the project and technological issues

The project of the No.2 Uenbetsu tunnel construction in Erimo Town on route 336 extends the existing Uenbetsu tunnel (3,215 m long) to eliminate the dangerous stretch prone to rock collapse triggered by heavy rainfall and avalanche. The new tunnel is about 1,927 m long. Once completed, the new and old tunnels will be combined into a single tunnel about 4,941 m long. First, a branch by the NATM was constructed in the existing road tunnel, from which the tunnel was excavated. To maintain the traffic essential for the life of local residents, it was necessary to keep at least one lane open even during construction of the branch. The challenge of this project was to complete the branch construction safely within a short period.

2. Solutions for achieving the targets

1) Ensuring safety of ordinary vehicles

The geology is mainly composed of medium-hard rock classified as hornfels of the Mesozoic era. For safe work, mechanical excavation with a breaker was selected. In addition, a travelling protector 24 m long was used to separate and protect a lane, maintaining ordinary vehicle traffic during construction of the branch.

2) Keeping the atmosphere clean in the existing tunnel

A mobile partition was installed at the enlarging position (end of the travelling protector), and a dust collector was provided with a telescopic ventilation pipe to forcibly remove dust from the work position. As a result, the dust concentration at the lane was kept at 0.5 mg/m^3 or less.

3) Shortening the section where traffic was controlled

The protectors were assembled and disassembled in a temporary yard outside the tunnel. They were carried by trailer trucks at night to minimize the time span of traffic control due to installation and removal of the protectors. Since the branching portion is a large flattened oval section, it was necessary to reinforce the support. The support was rationalized by using short bolts easy to place instead of long bolts and fiber reinforced plastic face bolts, to shorten the construction period. In addition, construction machines were changed and optimized so that they were well suited for the cutting sections. The branch excavation was completed in about six months from the start of the relocation of various facilities in the existing tunnel.

4) Verifying and ensuring stability of the tunnel structure

Displacement was measured in the branching section at intervals of 5 m. Additional measurements were made with extensometers and stress gauges, to verify the stability of the tunnel structure and design specifications. In the zone where the new tunnel is very close to the existing tunnel, after the existing tunnel was reinforced by filling the interstice between the two-lane stationary protector and the existing tunnel with concrete, stress gauges were mounted on the stationary protector to monitor the status. The measurement results were within the values predicted by the FEM analysis made in advance, posing no problem of tunnel stability.

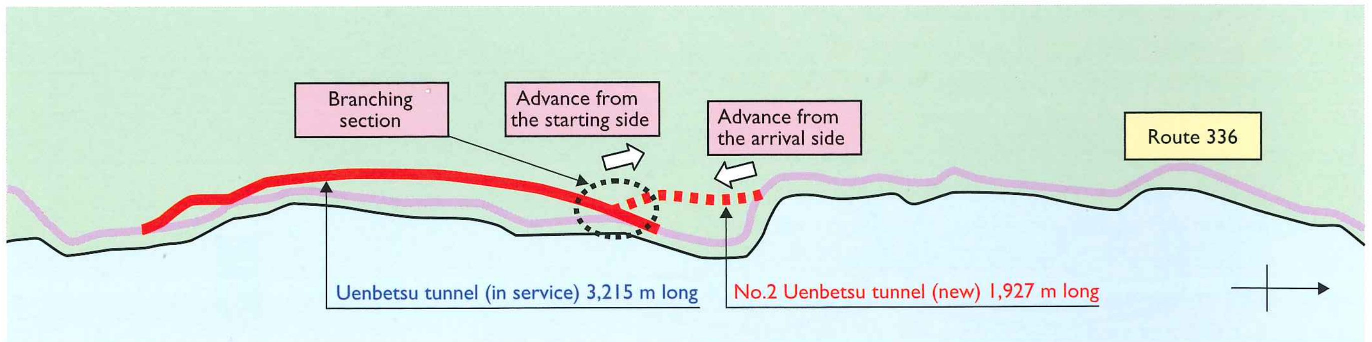


Fig. 1 Tunnel plan

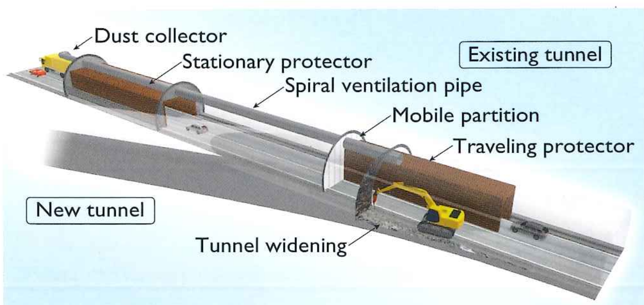


Fig. 2 Overall view of the branching section

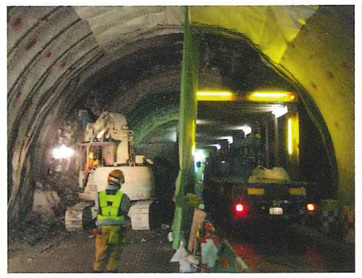
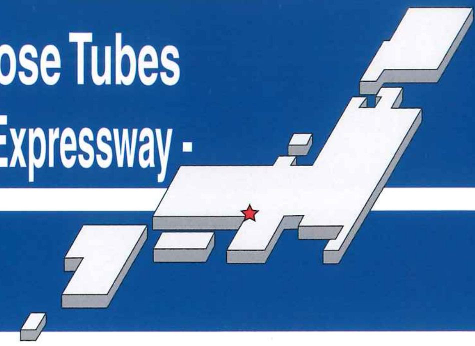


Photo 1 Excavation of the branching section

Photo 2 Excavation of the section close to the existing tunnel

A Long, Large-Section Twin Tunnel with Very Close Tubes - Shield Tunnel on the Yamatogawa Route of the Hanshin Expressway -



Atsushi SHIMURA

Assistant Manager
Construction Management Headquarters
Hanshin Expressway Company Limited

1. Overview

The Yamatogawa Route on the Hanshin Expressway is a motorway with a length of approximately 9.7 km that will form a part of a new loop road in the center of Osaka City. With consideration of various factors, such as the preservation of the scenery of the Yamato River, the environmental impact on the neighboring urban areas, and utilization of the land along the course of the Yamatogawa Route, underground and semi-underground structures are generally adopted except for the sections that will connect the Yamatogawa Route with existing routes. In the early planning stage, the cut and cover method was prescribed for the underground section of the route. However, for areas where a railway, a water purification plant and other important facilities are located above the planned construction sites, the construction method was changed to shield tunnel construction. This was facilitated by the advancement of the shield technology, which made the utilization of the shield tunneling method more economic and faster in terms of construction time. The tunnel structure of the Yamatogawa Route is shown in Fig. 1.

The shield tunnel system consists of two parallel single-track tubes 3.9 km long and a distance between the tubes of 1 m, and as such it has the structure of long-distance super-adjacent parallel shield tunnel tubes. Construction is carried out using the high-density slurry shield tunneling method, and the external diameter of the shield machine is 12.47 m. The shield machine prescribed in the plan for this project is shown in Photo 1. The horizontal curve of the route has a minimum radius of about 400 m and a maximum gradient of 3%. The plan envisions application of an articulated shield machine.

2. Technical characteristics of the shield tunnel

1) Long distance excavating

The shield tunnel is composed of two sections: one with a length of 1.9 km to be constructed by the Osaka Prefectural Government, and the other with a length of 2.0 km to be constructed by the Hanshin Expressway Co., Ltd. According to the plan, both sections are to be excavated with one shield machine each. After excavating the first tube, the shield machines will make a turn in the shaft and will excavate the second tube. The section to be constructed by the Osaka Prefectural Government will have a total excavation length of 3.8 km, and the section to be constructed by the Hanshin Expressway Co., Ltd. will have a total excavation length of 4.0 km, making the structure a long-distance shield tunnel.

2) Super-adjacent

The external diameter of the Yamatogawa Route Shield Tunnel is approximately 12.23 m (Fig. 2), and it has the structure of large-section super-adjacent parallel shield bores. If the segment external diameter is D, then the minimum distance between the tubes is 0.08D. Construction of a shield dual bore tunnel that involves excavation work at such a close proximity and for such a long distance is unprecedented even in Japan, so the impact of parallel tunneling that takes into consideration the excavation construction process is being analyzed in advance using FEM.

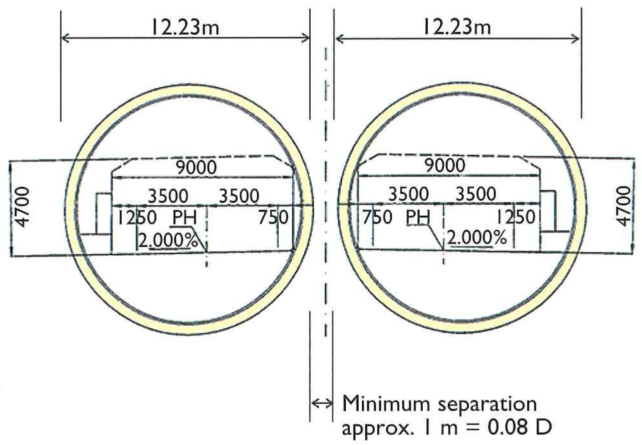


Fig. 2 Shield section and distance between parallel bores

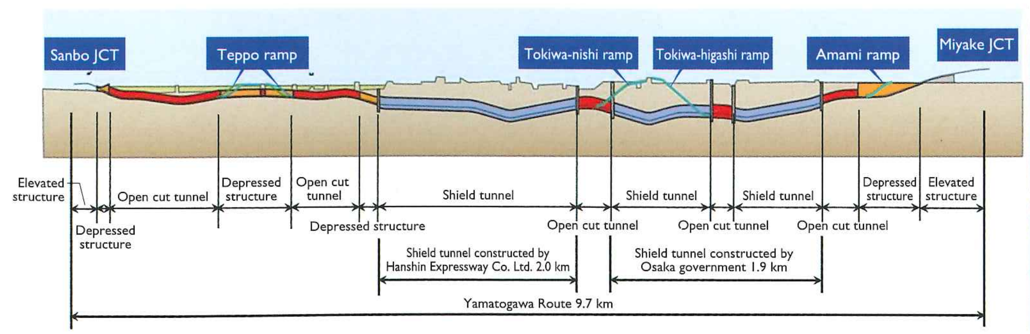


Fig. 1 Tunnel profile of the Yamatogawa Route

Photo 1 Shield machine

H&V Shield Tunneling of a Sewer Main for Flood Protection

Masashi KESUDA
Director, Design Section
Core Facilities Reconstruction Office
Bureau of Sewerage, Tokyo Metropolitan Government

1. Introduction

In Tokyo's 23 wards, the percentage of population with sewer service reached 100% in 1995. However, due to an increase in storm water runoff volume due to extensive urbanization, the flow capacity of sewers is insufficient, resulting in frequent flooding. Since in the Tameike, Yotsuya and Akasaka districts, at the center of Tokyo, inundation has occurred frequently, extensive measures against floods have been required. Under the circumstance, it was decided to construct new sewer mains (rainwater ducts).

2. Selection of the H&V shield

The sewer mains of this project will be bored by shield tunneling. Because of restrictions imposed on the work period and land for construction, it is necessary to start the shield machine for boring two mains from a single shaft. Therefore, the H&V (Horizontal variation & Vertical variation) shield method (double-face branching shield) was selected.

The H&V shield features the following advantages:

1) Ability to bore tubes extremely close to each other (distance as small as 150 to 350 mm).
2) Each bore is basically circular, which is mechanically advantageous, offering excellent structural stability and cost performance (it is unnecessary to increase rigidity of segments and improve ground).
3) Separation in the underground of the H&V shield makes it possible to make a branch bore without constructing a shaft.

The Bureau of Sewerage of the Tokyo Metropolitan government used the H&V shield in the project of the Minami-dai main (2,400 mm in finished I.D.) and Minami-dai-nishi main (2,000 mm in finished I.D.). The present project is the second example.

The finished inner diameter of the two mains of this project will be 8,000 mm and 3,500 mm respectively. Simultaneous start of the double-shield of such a large diameter and a diameter ratio as large as 2.5 is unprecedented in Japan. Each shield has an independent cutting system and an independent mucking mechanism. The shields can be separated by removing from the machine inside the connecting pins of the front cylinder and the joining bolts of the rear cylinder. The sewer mains are about 2.5 km long and 1.0 km long respectively, branching at 300 m from the start. Shield excavation will commence in the beginning of 2011.

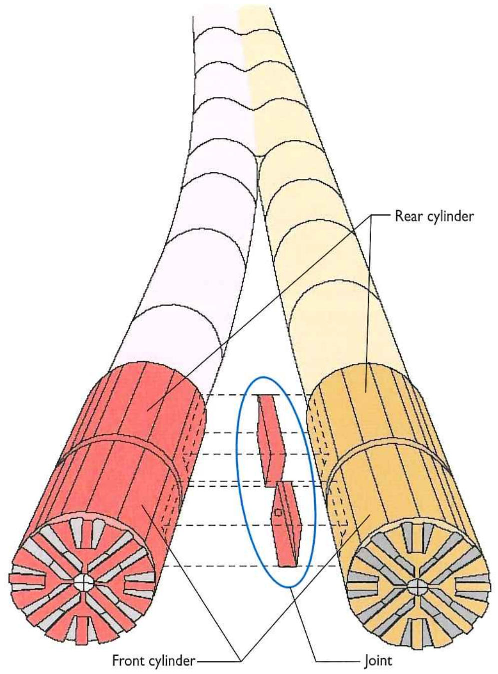


Fig. 1 Schematic view of branching

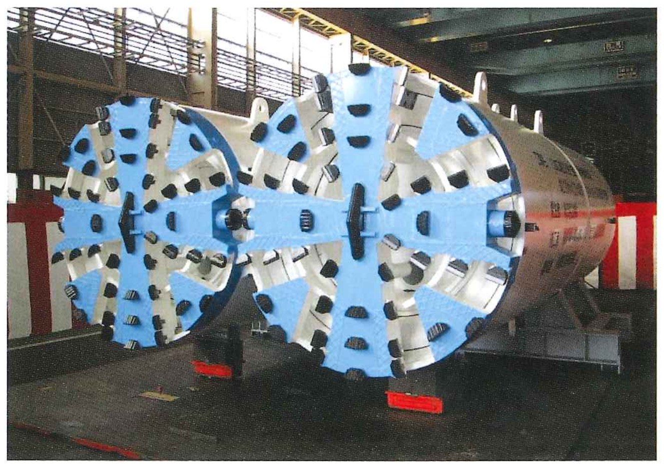


Photo 1 Twin multi-head shield for horizontal tunnels
(ϕ 2,090 mm x 2)

Photo 2 Twin multi-head shield for stacked tunnels
(upper: ϕ 3,290 mm, lower: ϕ 2,890 mm) (Minami-dai sewer main)

Upward Shield Tunneling Method Adopted for Urban Areas - Meieki-minami Storm Water Primary Drain -

Nobuyuki HARA
Manager
Meiekiminamiusuikansen Site Office
Nagoya Branch, Taisei Corporation

1. Project overview

The Meieki-minami Storm Water Main Drain is a storm water storage pipe constructed as part of the anti-flood measures for the area around Nagoya Station.

The conventional shield method bores a tunnel horizontally from the starting shaft to the arrival shaft. However, in this project the area where it was necessary to build an arrival shaft had insufficient space for aboveground construction, a large traffic volume, and a high concentration of commercial facilities. This made shaft construction from above impossible. That is why it was decided to adopt the upward shield tunneling method, which makes it possible to leave the shield machine used in the boring of the horizontal shaft in the ground near the arrival point, assemble a new shield in the existing tunnel and then bore a shaft from the bottom up. This method was used for the construction of two shafts: one for inflow of rainwater, and one for drainage.

This project is the second case of utilizing the upward shield tunneling method for construction of shafts.

The lengths of the primary lining of the inflow shaft and the drainage shaft are 19.44 m and 24.44 m, respectively. Two caisson type piles with a diameter of 4,500 mm were built for the arrival.

2. Upward Shield Tunneling Method

Prior to the launch of upward shield boring operations, a caisson type pile is excavated from above the ground in preparation for the shield arrival.

The upward shield is transported and assembled in the horizontal shaft and is then used to bore a shaft from the bottom up to the arrival caisson type pile. After arriving at that point, the shield is removed from above the ground, transported back to the horizontal shaft and used to bore the second shaft.

The upward shield used in this project is a pressurized high-density slurry shield with an external diameter of 3,110 mm.

The cutter advances by directly cutting the opening segments installed in the horizontal shaft, so its shape is adjusted to match the internal curve of the horizontal shaft (Photo 1).

The segments for the opening are made of materials that can be directly cut with the shield cutters.

In this project, two types of material were used in the segments for the opening: NOMST (Novel Material Shield-cuttable Tunnel-wall System) material made of concrete reinforced with carbon-fiber rods, and FFU (fiber-reinforced foamed urethane) material made by, laminating synthetic wood made of rigid foamed urethane reinforced with long glass fibers.

The pinch valve is built so that air is supplied to expand a rubber sleeve installed inside the mud slurry discharge pipe, thereby closing this pipe. This system controls face earth pressure and slurry discharge volume (Fig. 1).

3. Future development

Compared to the method for shaft boring from above, the upward shield tunneling method makes it possible to reduce both construction space aboveground and construction time. That is why it is considered effective for projects in densely populated urban areas with insufficient space for aboveground operations. In the future, changes in the construction environment and greater congestion of underground facilities caused by the progress of urbanization are expected to result in an increase of deep subterranean construction projects. In view of these trends, it is necessary to carry out further technical examination and practical verification.

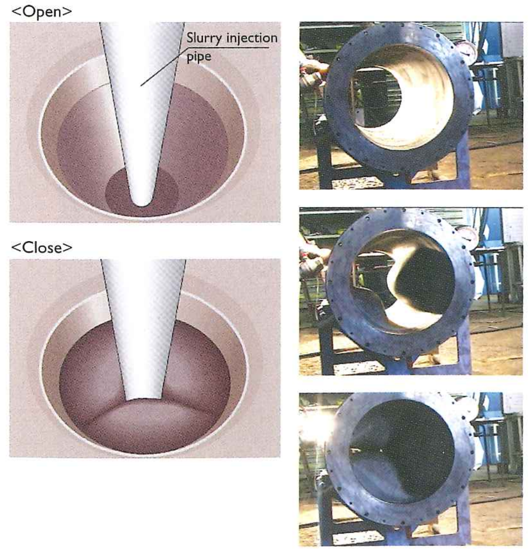


Fig. 1 Pinch valve

Photo 1 Upward shield

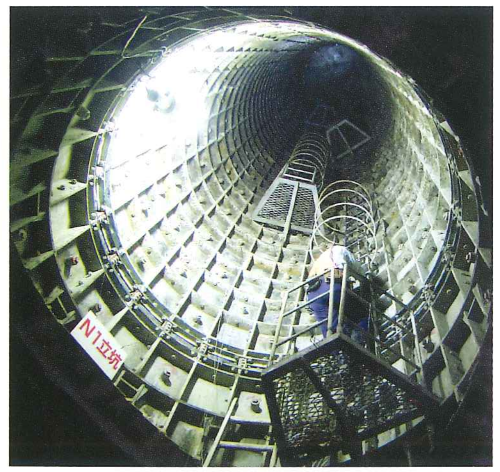


Photo 2 Completion of tunneling

Application of Nested Parent-Child TBM
- Construction of Two Shield Tunnels with Different Diameters Using One TBM -

Hidenori SHIMIZU
Chief of the Engineering Works Department (2nd), Hamamatsu Office of River and National Highway, Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

1. Introduction

Each utility line such as power, water, gas, telecommunications etc. used to be planned and constructed by the various agencies and companies. The Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, is a project owner working on the construction of utility tunnels containing various types of utilities in order to make more efficient use of underground space, mitigate traffic congestion due to repeated excavation for construction of each utility, and ensure stable supply of energy in normal times and during emergencies. A 3.67 km-long section in the Seishin utility tunnel project (total length of 12.8 km) in Shizuoka, was originally designed with a shield tunnel section and cut and cover tunnel section with different diameters. Since construction of the cut and cover tunnel needed to excavate part of heavily traveled Route 1, an alternative method was requested to change the design from the C/C tunnel section to shield tunnel section and to drive entire sections using the TBM in order to achieve the least impact on traffic on this arterial road.

2. Application of Nested Parent-Child TBM

The alternative design, however, created a new problem that there were two diameters (4.25m and 5.71m) to be driven by the TBM. Need two TBMs? The solution was to use one "nested parent-child" TBM, which has the ability to drive two different size tunnels by using an inter-lockable technique.

The "child" machine used in the narrower tunnel section was locked into the doughnut-shaped "parent" machine that continued driving the wider tunnel.

3. Effects of Nested Parent-Child TBM

The Nested Parent-Child TBM method reduced 1) the length of the cut-and-cover tunnel section from L= 1,010 m in the original plan to L= 16.0 m (length of intermediate shaft) and 2) construction period of TBM diameter enlargement work, and the following benefits were realized:

(1) Minimization of environmental impact

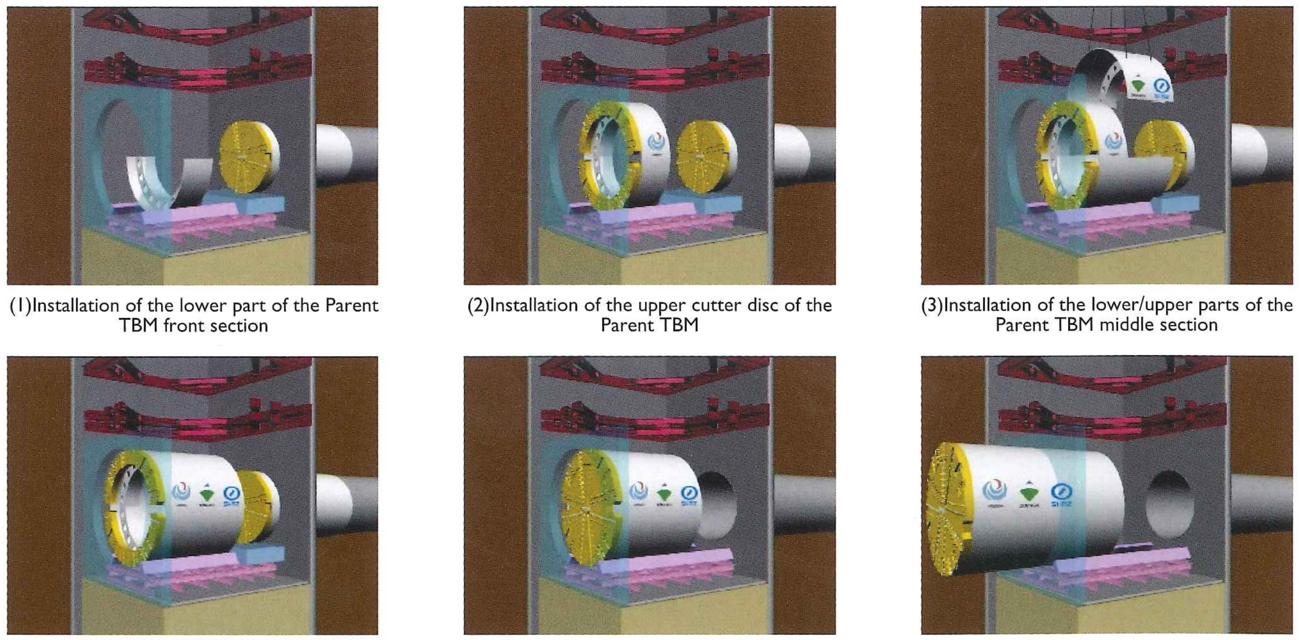
The construction with the shield tunnel method over the entire tunnel section minimized the impact on the living environment of roadside residents, i.e. minimization of noise/vibration, disruption of the road and narrow pedestrian passage due to road diversion.

(2) Minimization of impact on traffic

The number of days the road had to be closed was drastically reduced by 137 days from the original plan.

(3) Saving and recycling of materials and resources

The substantial reduction in the length of the cut-and-cover tunnel section eliminated the need to relocate numerous underground facilities and utilities and reduced excavation work and industrial waste such as asphalt debris. Furthermore, the Nested Parent-Child TBM has reduced the quantity of materials of the shield machine and contributed to saving resources as well.



(1)Installation of the lower part of the Parent TBM front section
(2)Installation of the upper cutter disc of the Parent TBM
(3)Installation of the lower/upper parts of the Parent TBM middle section
(4)Insert the Child TBM to the Parent TBM
(5)Completion of the insert
(6)Departure of the Parent TBM

TBM diameter enlargement process

Fig. 1 TBM diameter enlargement process

Information-Oriented Construction of the Kyogoku Underground Power House

Tetsuji NISHIMURA
Section Manager, Low Reservoir & Powerhouse
Kyogoku Project Office
Hokkaido Electric Power Co., Inc.

1. Introduction

The Kyogoku Power House is a pure pumped-storage power generation plant of 600 thousand kW (200 thousand kW/generator unit x 3 units) with an effective head of 369 m, provided with upper and lower de-sanding basins linked with each other by a channel about 3 km long.

The underground power plant is located deep with 430 m overburden. It has a bullet head shape 45.8 m high, 22 to 24 m wide and 140 m long (Fig. 1).

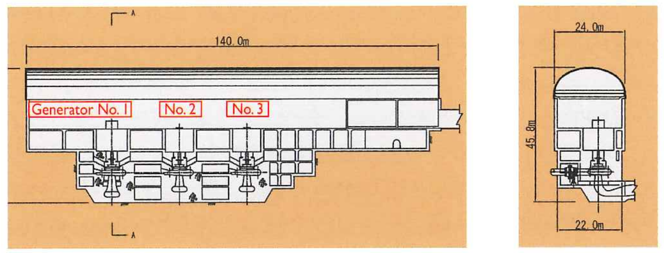


Fig. 1 Structure of the underground power house

2. Design of the underground power plant and information-oriented construction plan

The bedrock around the cavern is mainly composed of tuff breccias of Miocene epoch of Neogene period, with sparse tuff blocks. The rock class is generally CH and hard rock (approx. 100 MPa in unconfined compressive strength). However, along the fault lies a zone with minimal strength (approx. 30 to 40 MPa in unconfined compressive strength). Therefore, the bedrock was evaluated as CH' class. The lateral pressure coefficient is as large as 1.73.

The support design was classified into that for the standard section of CH class bedrock and that for the fault and altered zone of CH' class bedrock (Fig. 2). The supports used were shotcrete, rock bolts and PS anchors.

The cavern was planned to be bored in 16 steps, including 2 steps for the arch (top drift cutting and enlargement), 14 steps for spreading (a bench 2.5 m). Information-oriented construction is performed by means of geological survey and measurements. The geological survey utilized a visualization system of geological structure and construction status, and face observation results were stored in a database to represent the geological structure by 3D computer graphics (Fig. 3). Bedrock displacement gauges, anchor load cells and rock bolt axial force meters were installed in seven sections in the longitudinal direction of the cavern to monitor bedrock behavior and stresses in the supports by means of a measurement management system.

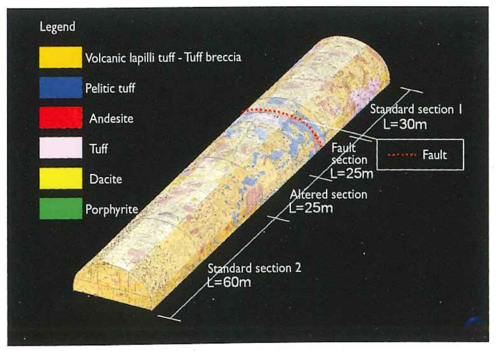


Fig.3 Geological structure of the arch by 3D computer graphics

3. Current status of the information-oriented construction

Excavation of the arch started in January 2009. The top drift was completed in March 2009 and enlargement was finished in November of the same year. Generally, the geology turned out to be as expected. Cutting for spreading will be carried out for about 11 months from January 2010. Monitoring will be continued for the bedrock behavior and integrity of the supports, validating the design. In addition, back analysis will be made, utilizing the measurement results, thereby achieving an even more rationalized support design.

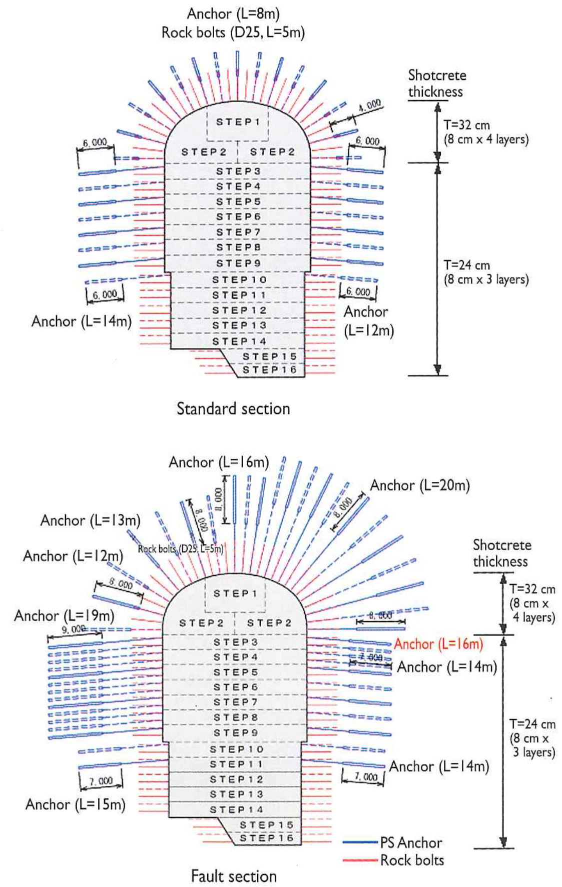


Fig. 2 Excavation steps and support pattern

Construction of Inclined Tunnels and Vertical Shafts Under the Sea - Intake Tunneling for Shimane Nuclear Power Plant Unit 3 -

Tsuyoshi OHMURA
Section Chief,
Shimane Nuclear Power Plant
Chugoku Electric Power Co., Inc.

1. Project overview

At the Shimane Nuclear Power Plant, an additional generator, Unit 3 (1,373MW), is under construction, which is planned to be ready for commercial operation in December 2011. To draw cooling water from the sea, an undersea tunneling method is employed because environmental impact is small and work is possible in all seasons compared with laying steel pipe on the seabed. The undersea intake tunnel, which connects two intake caissons (26MN dead weight ea.) with the box culvert intake channel, is 300 m long and 20 m below the bottom of the Japan Sea (40 m below sea level). Tunnels consist of departure shaft (12 m in diameter, 35 m in height), main intake tunnel (finished cross section 48 m^2, 237 m in length, gradient 16%), branch intake tunnel (finished cross section 36 m^2, 35 m in length, gradient 0%) and two vertical shafts (5.5 m in diameter, 18 m in height). All tunnels and shafts are excavated by NATM with blasting methods in black shale and tuff (unconfined compressive strength 26 to 162 N/mm^2, coefficient of permeability 10^{-3} to 10^{-5} cm/sec).

2. Measures against problems in tunneling

1) Immense amount of sea water ingress

An excessive water inflow causes serious problems not only during excavation but also for the lining. Therefore, pre-grouting ahead of the face is performed for dewatering around tunnels (5 m thick) and shafts (7 m thick). Cutoff target value is 1.4 Lu or less and specific discharge of springs is 0.4 to 0.6 liters/min/m. Grouting material selected was an ultra-fine special slug. This material has a high durability resistant to seawater and a high consolidation strength, penetrating well even into fine cracks, with an adjustable gelling time to prevent seawater contamination. Two-stage grouting ahead of the face was repeated in tunnels. In shafts, primary rough grouting was applied, and then secondary grouting was performed upward in three stages. To automatically monitor floating of the intake caissons under grouting pressures, two inclinometers and two displacement sensors were installed. Control criterion is 0.2 mm or less per one stage.

2) Draining the tunnel with 16 % downward gradient

Water inflow left pools in the tunnel face because of the downward tunnel gradient. Therefore, a suction pump (lift height 65 m, discharge rate 0.5 m^3/min) placed at the tunnel face, carried water inflow into the turbid water treatment plant (60 m^3/hr, on the ground) via an evacuation reservoir pit (10 m^3, under the tunnel floor). When the total volume of water inflow increased to 40 m^3/hr, water cutoff grouting was started to reduce the inflow. Thereafter, clear water was separated from turbid water and discharged into the sea directly. To make doubly sure of prevention of tunnel submergence due to pump trouble, two emergency sets of generators and spare pumps were ready on hand.

3) Upward excavation of undersea shaft

Intake shafts were excavated by raise drifting to the caisson inside using an Alimak Raise Climber and downward enlargement from that point. The Climber carried a remote controllable hydraulic rock drill and spraying device. Safety measures such as work scaffold-cum-protector equipment, stationary camera monitoring, radio communication system by throat microphones etc. had been taken during shaft excavation.

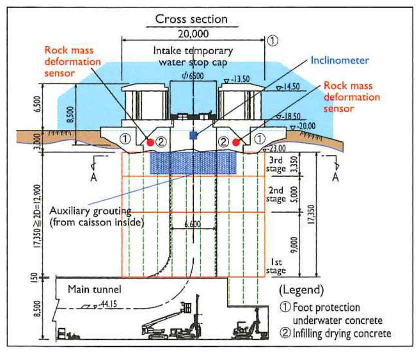


Fig. 2 Grouting scheme of intake shaft

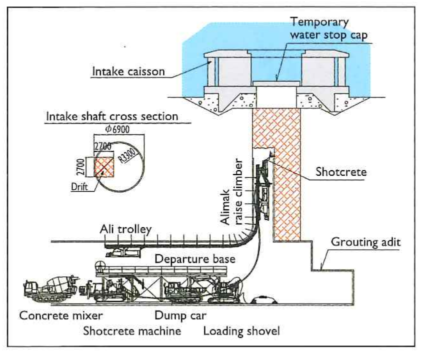


Fig. 3 Excavation scheme of intake shaft drift

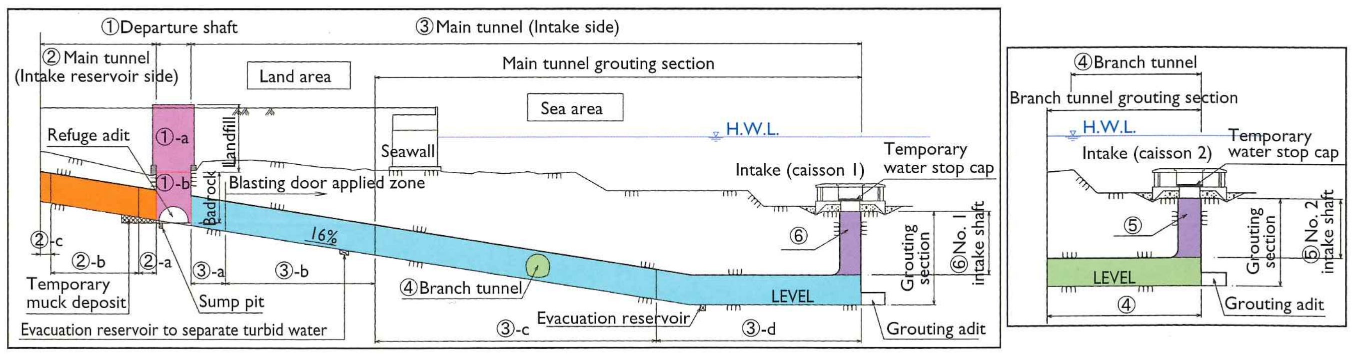


Fig. 1 Construction procedure of intake tunnel

Construction of a Tunnel Utilizing a 150-meter Pipe Roof - Construction of a Grade-Separated Crossing on Route 9 -

Kentaro KOBAYASHI
Director of Kyoto National Highway Office
Ministry of Land, Infrastructure, Transport and Tourism

1. Overview of the tunneling project

Route 9 is a major highway linking Kyoto City and Western Japan. The crossing of Route 9 at Chiyoharaguchi is located in the western area of Kyoto. In order to ease chronic congestion at this point and to create a comfortable and safe road environment, the existing intersection is currently being rebuilt into a grade-separated intersection.

This project plans constructing the section 490 m long at the Chiyoharaguchi intersection into a grade-separated crossing, and for the length of a 150 m section extending over the crossing, the tunnel was bored with the non-open cut method utilizing a pipe roof (the longest in the world). This approach was known to have appropriate technical reliability, less impact on the surrounding environment and good economic efficiency.

2. Construction

For the pipe roofing project, we were confronted with overcoming the following difficult conditions:

- The Tunneling work should not hinder the current traffic.
- The geology under the national highway is composed of an aquifer gravel bed over a long distance, and the earth covering is small.
- The tunnel structure to be bored is very large in section.
- There were many buried objects such as power ducts.

In addition, through survey of the site ahead of the tunneling, the positions of buried objects were found to be different from those we had presumed, and there remained obstacles such as driven sheet piles. The work procedure is currently organized in the following order: 1) construction of earth retaining system, 2) construction of the shaft, 3) construction of the pipe roof, 4) excavation beneath the pipe roof, 5) construction of supports in the area of the pipe roof, 6) construction of main structures, 7) filling the clearance between the pipe roof continuum and the main structure by grouting.

The number of roofing pipes driven was 36 (27 pipes of 80 cm in diameter, 9 pipes of 1 m in diameter), and 32 pipes were driven into the ground by a slurry shield propelling machine, and the portion for placement of two pipes of 1 m diameter was bored with human labor. For the construction of a 150 m pipe roof, the use of an alignment management system made it possible to achieve excellent safety and accuracy and to control errors within 10 cm against the planned alignment, both vertically and horizontally.

The overburden was 3.5 m. For the control of ground subsidence due to the presence of a clearance of 30 mm between the overbreak and the continuum of the pipe roof, we used a filler especially developed. Thanks to this material, we could control the size of subsidence to less than 8 mm.

In addition, this tunneling project was designed with a large section (excavation height 10 m x width 17 m), which allowed reduction of the standard process burden by 30%, and support material volume by 30%. With regard to the treatment of ground water, we used an underground water control system which reduced the volume of pumped water by 35%, and no adverse effects such as water deficiency in wells in the surroundings were reported.

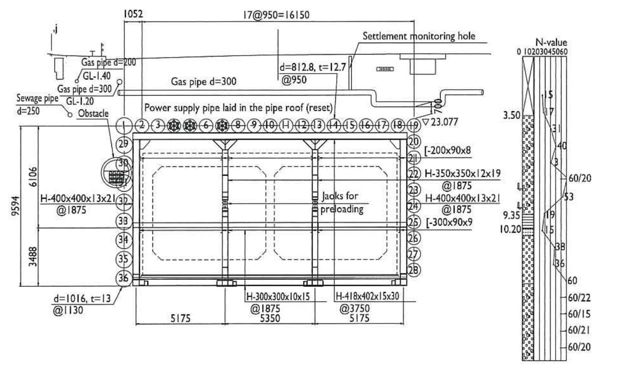


Fig. 2 Cross section of non-open-cut section

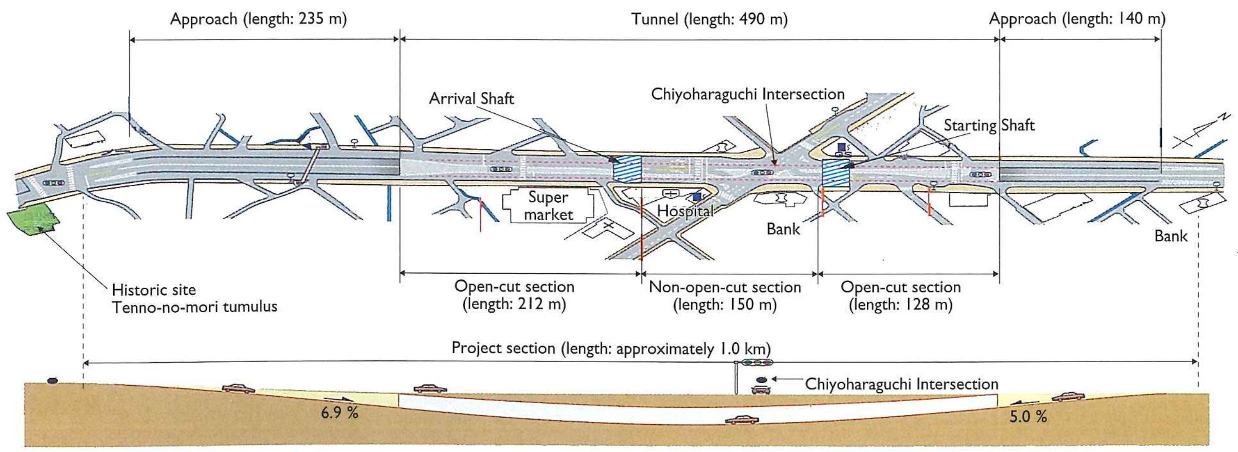
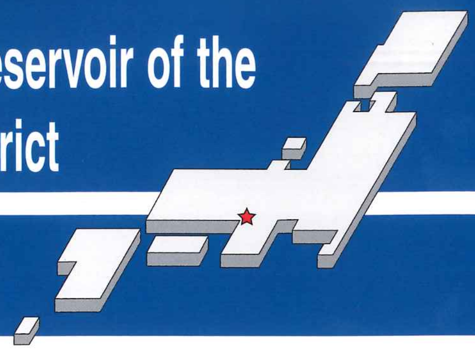


Fig. 1 General plan and longitudinal profile

Shield Tunneling for the Kitajima Regulating Reservoir of the Underground River in the Neya River North District



Shoji KATADA

Senior Staff
Neyagawa River-Basin Flood Control Office
Osaka Prefectural Government

1. Overview of the Neya River basin and comprehensive flood control

The Neya basin is located in the east of Osaka Prefecture. Of its area of 267.5 km^2, about 75% is lowland. Rapid increase of population and urbanization from the second half of the 1950s changed this district into an urban area with dense population of 2.60 million. As a consequence, rainwater runoff increased, exceeding the flow capacity of the river, presenting a risky situation.

Under these circumstances, the "Neya river basis comprehensive flood control plan" (max. hourly rainfall 62.9 mm, max. 24-hr rainfall 311.2 mm) was drawn up in 1990. This plan included not only enlargement of river width but also construction of new flood control facilities such as water reservoirs and an underground river tunnel for water discharge.

The following describes the construction of the Kitajima regulating reservoir that is the principal facility of the Neya river basin comprehensive flood control plan.

2. Shield tunneling

The slurry shield machine for constructing the Kitajima regulating reservoir started from the existing Kitajima shaft in the downstream direction, excavating a length of about 1.7 km with a finishing inner diameter of 5.4 m, to the position on the Furukawa regulating reservoir where the shield machine will be docked underground with another shield machine left there. The geology of the site is alternate Diluvium strata of gravel, sand and clay. It is therefore necessary to control excavation and suitably adapt it to geological variations.

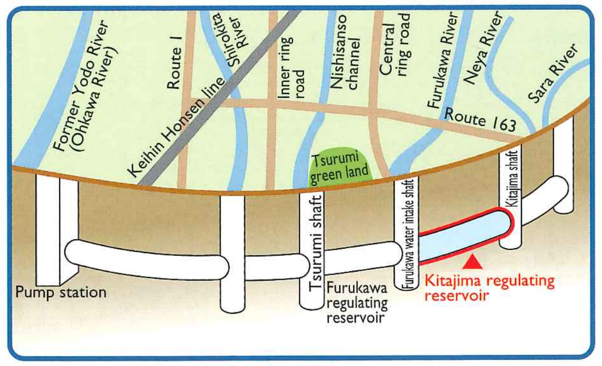


Fig. 1 General diagram of the underground river in the Neya River north district

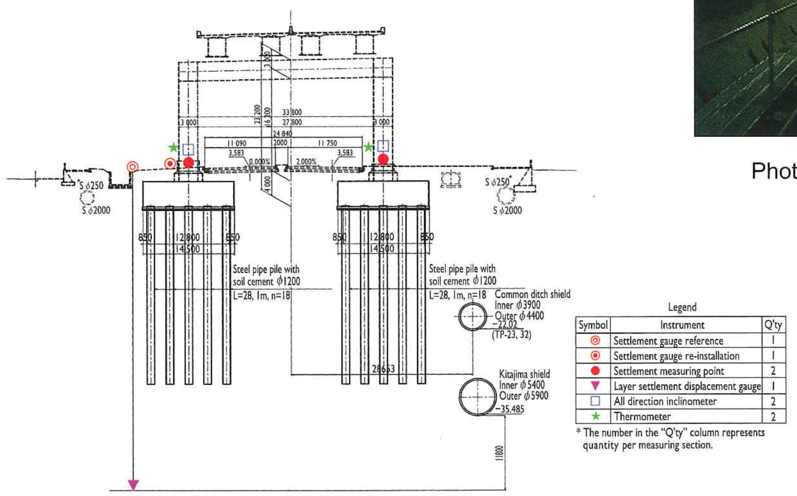


Fig. 2 Sectional drawing of measurement-oriented tunneling

3. Measurement-oriented tunneling

The shield tunneling site is near an elevated motorway. To minimize displacements of the motorway, ground behavior was measured in three sections for validating the control reference values for excavation and monitoring ground displacements.

During shield tunneling, ground settlement and inclination are automatically measured. As of the end of November 2009, displacements measured were within the control admissible value, proving satisfactory tunneling.

4. Underground docking

After the shield machine arrives at the Furukawa shaft, the equipment inside the machine will be removed for docking with the remaining shield of 8.0 m diameter. To perform the docking safely, soil freezing was selected, which builds a frozen soil wall around the docking position. The frozen soil wall has excellent water shield performance and strength, contributing to safe work during docking.

Immediately after the frozen soil is made, the bulkhead and cutter head are removed, and primary lining is placed. The inside surface of the skin plate is treated with secondary lining to complete the tunnel with different diameters.

Photo 1 Inside the shield tunnel

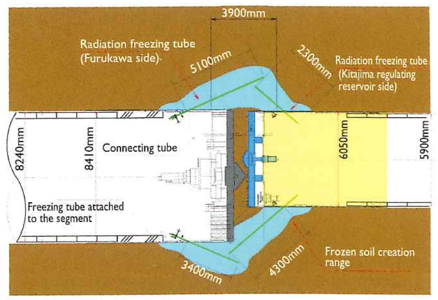


Fig. 3 Frozen soil creation range

Innovations in Technology

T-FREG (Tunnel Fiber Reinforced Edging)

Cracks and floating that occur in the lining concrete of the arch of mountain tunnels, may induce concrete spalling as the tunnels age and could cause injuries of third parties. To prevent such accidents, anti-spalling measures are taken. Inner surface reinforcement with adhesive fiber sheets is an example of a preventive measure.

The T-FREG is a new anti-spalling technique. This method fixes a fiber sheet over the inside of a sliding form before placing concrete, thereby forming concrete closely combined with the sheet. The performance of fiber sheets was validated by flexural rigidity and punching tests. Based on the test results, "alkali-resistant glass fiber sheet" was selected. This kind of sheet embedded in the concrete form will offer a satisfactory anti-spalling property. This sheet is also satisfactory in terms of fire resistance for application to tunnel structures, conforming to the building code of Japan.

The ordinary compaction technique can be used with this sheet when placing lining concrete, to make a fiber-sheet-concrete system not prone to spalling.

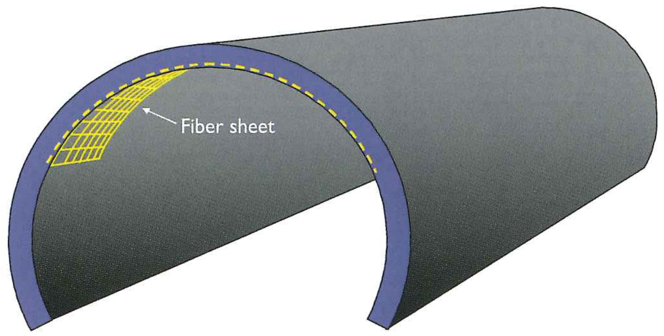


Fig. 1 T-FREG method

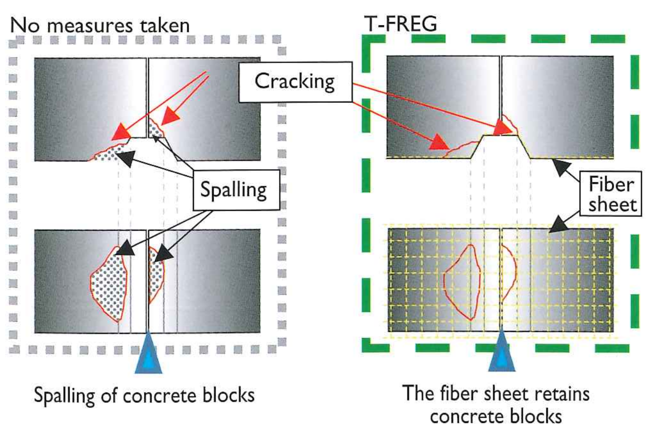


Fig. 2 Spalling

High-performance SFRC Segment

The high-performance SFRC (Steel Fiber Reinforced Concrete) segment is made of self-compacting high-fluidity concrete mixed with steel fibers.

Because of the reinforcing effect of steel fibers in this segment, high quality segments can be made with less primary reinforcement, and with no distribution and hoop reinforcements, that are also free from spalling at the segment end. Cracks in this type of segment are dispersed, thereby limiting the cracking width. Steel fibers rarely corrode except in the surface layer, decreasing corrosion of reinforcement in the concrete. Therefore, this segment has excellent durability.

Manpower is saved in the production steps such as re-bar fabrication and assembly, since less reinforcement is necessary. No table vibrator is necessary with high-fluidity concrete. This alleviates vibrating noise during fabrication, reducing environmental impact. Segments can be therefore fabricated on construction sites.

Photo 1 SFRC segment

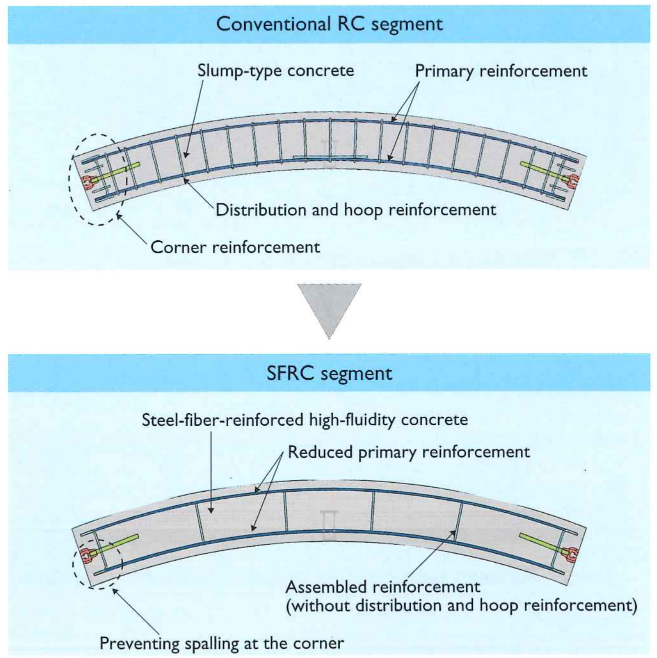


Fig.1 Comparison between SFRC segment and conventional RC segment

Innovations in Technology

Ultrasonic humidifying curing system

In construction of new tunnels, no additional curing of lining concrete has usually been made after removing the forms. As a result, cracks are caused mainly by sudden drying and temperature dropping at the surface of concrete after form removal, due to ventilation during excavation and drafts after breakthrough of the tunnel.

The ultrasonic humidifying curing system forms a closed space with a curing sheet over the lining concrete surface after form removal, and humidifies the air in the closed space and keeps the concrete surface at a suitable temperature. Ultrasonic waves pulverize water into fine particles to be discharged. This system does not need water temperatures to be controlled, enabling effective curing.

Use of this system in new tunnel construction projects will prevent cracking in concrete due to drying shrinkage and thermal cracking, thereby offering improved quality and longer durability of structures.

(Contact:akiyoshi.kenji@obayashi.co.jp)

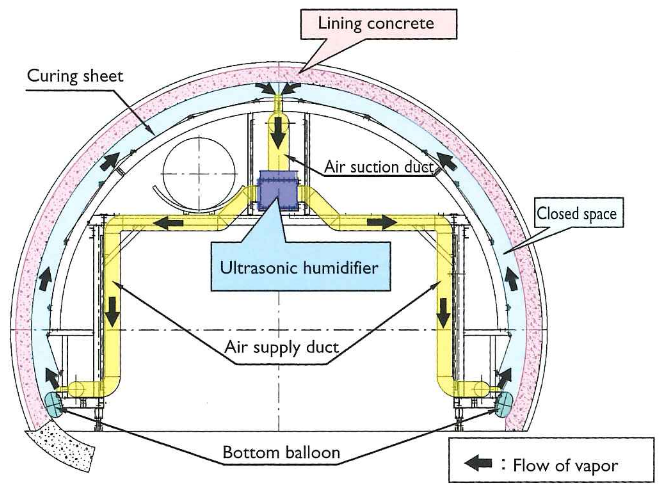


Fig. 1 Cross section of the system

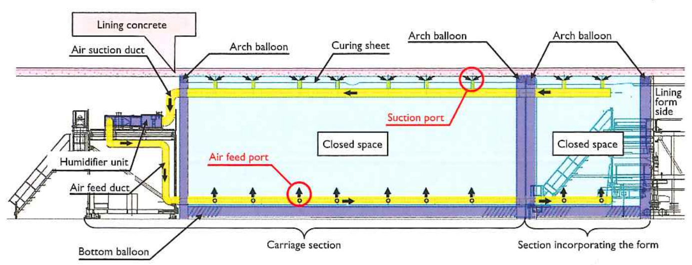


Fig. 2 Longitudinal section of the system

Ground cutting JES method

The ground cutting JES (Jointed Element Structure) method constructs an underpass below railway tracks. This method can be used even in a site with an overburden as small as one meter, limiting surface displacement within a non-significant range.

In this construction method, a cutting wire provided on the blade assembly cuts ground, rubble and other obstacles, while small-section steel elements are inserted in the ground. The elements that are placed in the ground are filled with concrete to form a permanent structure. Forces are transmitted between the elements via special joints (JES joints). Even if unexpected obstacles such as boulders exist in the ground, elements are placed while cutting the obstacles. Therefore, upheaval of obstacles does not occur during element insertion and no void is produced in the ground because of removal of the obstacles. Consequently, this method limits ground surface settlement and heaving.

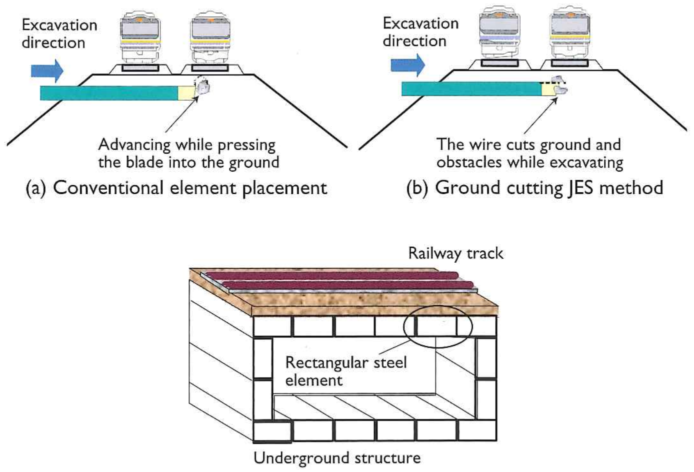


Fig. 1 Element placing method

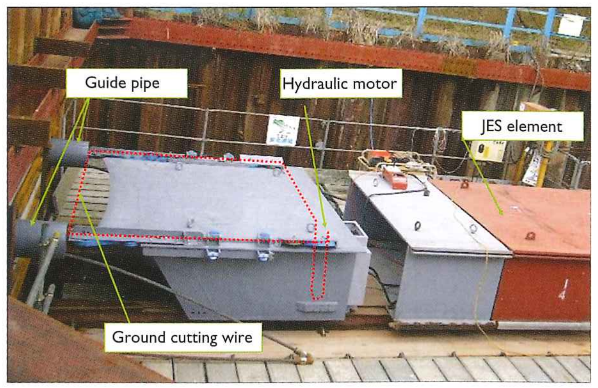


Photo 1 Ground cutting JES method

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. Fig. 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.

Fig. 2 shows the makeup of contracted amounts of different project purposes in 2009. The largest was road at 52%, followed by water channel at 27%, railway at 11% and others at 10%.

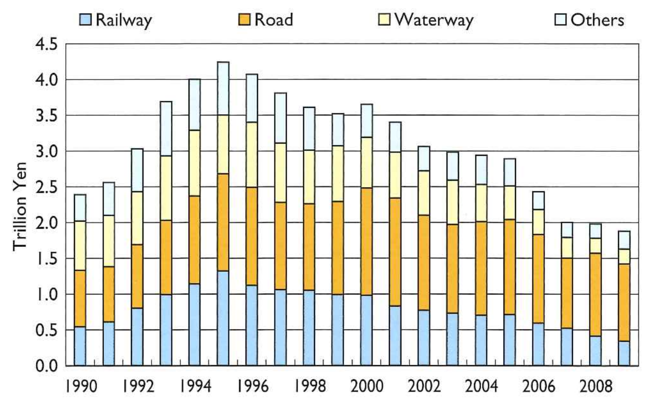


Fig. 1 Trend of construction investment in tunnels and underground space

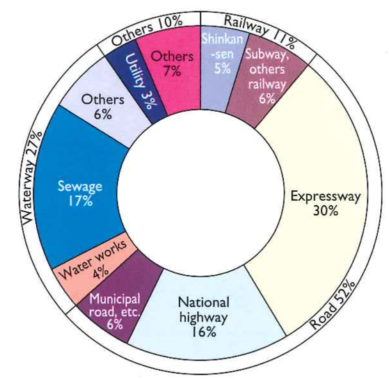


Fig. 2 Ratio of contractual amount by project purpose

Trends of Tunneling Method

Fig. 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 has leveled 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.

Fig. 4 illustrates the percentages of different construction methods and those of excavation methods. The conventional method accounts for 57% of the total, for which blasting is most frequent, 64%. The shield method is 22%, which is subdivided into 27% for slurry shield and 66% for mud slurry shield and 6% for earth pressure balanced shield.

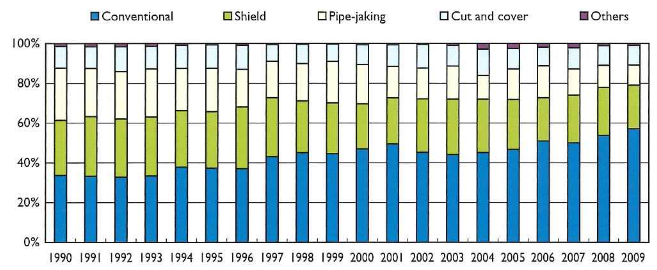


Fig. 3 Ratio of tunnel numbers by excavation method

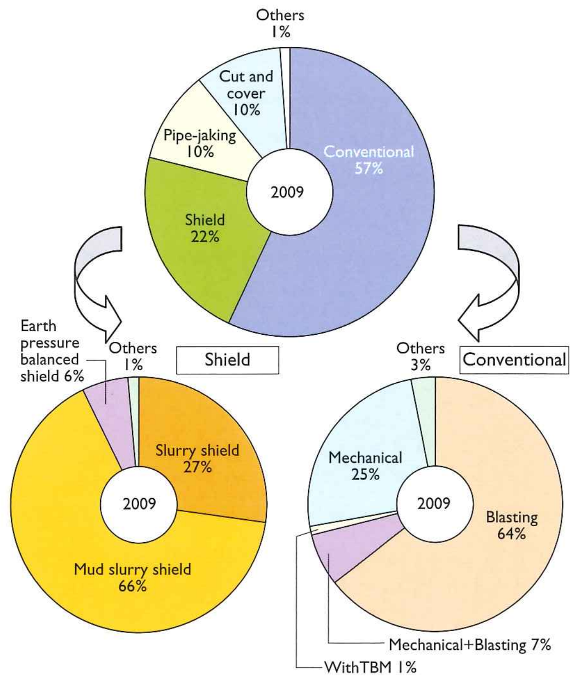


Fig. 4 Breakdown of construction and excavation methods

Overseas Tunnel Construction by Japanese Contractors

Fig. 5 shows the contract amounts of overseas tunnel construction projects by JTA member contractors. The amount has been gradually increasing since 1994.

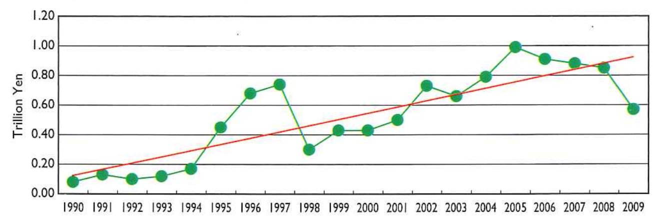


Fig.5 Overseas tunnel construction by Japanese contractors

Authorities and Owner Companies

Central Nippon Expressway Co., Ltd.
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

East Nippon Expressway Co., Ltd.
3-3-2, Kasumigaseki, Chiyoda-ku, Tokyo 100-8979
TEL: 3-3506-0111
http://www.e-nexco.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 Metro Co., Ltd.
3-19-6, Higashi-Ueno, Taito-ku, Tokyo 110-8614
TEL: 3-3837-7132 FAX: 3-3837-7122
http://www.tokyometro.jp/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

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
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

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

List of Members

Okumura Corporation
2-2-2, Matsuzaki-cho, Abeno-ku, Osaka-shi, Osaka 545-8555
TEL: 6-6621-1101 FAX: 6-6627-5295
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/

Sato Kogyo Co., Ltd.
4-12-19, Nihonbashi-honcho, Chuo-ku, Tokyo 103-8639
TEL: 3-3661-0502 FAX: 3-3661-5473
E-mail: skip@satokogyo.co.jp http://www.satokogyo.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.
5F, Rivercity M-SQUARE, 2-1-6, Tsukuda, Chuo-ku, Tokyo 104-0051
TEL: 3-4582-3053 FAX: 3-4582-3217
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

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

Tobishima Corporation
2, Sanban-cho, Chiyoda-ku, Tokyo 102-8332
TEL: 3-5214-8200 FAX: 3-5276-2526
http://www.tobishima.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.
2-4-24, 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 150-0031
TEL: 3-3476-5701 FAX: 3-3476-4551
E-mail: gijutsu@jafec.co.jp http://www.jafec.co.jp

SANSHIN CORPORATION
2-19-6, Yanagibashi, Taito-ku, Tokyo 111-0052
TEL: 3-5825-3700 FAX: 3-5825-3566
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
TEL: 3-3842-9170 FAX: 3-3842-9177
E-mail: jtc@jtc-con.co.jp http://www.jtc-con.co.jp

JR East Consultants Company
Metropolitan Plaza Bldg., 1-11-1, Nishi-Ikebukuro, Toshima-ku, Tokyo 171-0021
TEL: 3-5396-7221 FAX: 3-5949-2791
E-mail: hdoi@jrc.jregroup.ne.jp http://www.jrc.jregroup.ne.jp

METRO DEVELOPMENT CO., LTD
11-9, Nihonbashi-kodenmacho, Chuo-ku, Tokyo 103-0001
TEL: 3-5847-7800 FAX: 3-5847-7821
E-mail: gijutsu1@metro-dev.co.jp http://www.metro-dev.co.jp

List of Members

Nexco-Engineering Tohoku Company Limited
13F, Kakyoin Plaza, 2-1-65, Kakyoin, Aoba-ku, Sendai-shi, Miyagi 980-0013
TEL: 22-713-7277 FAX:22-263-1422
http://www.e-nexco-engito.co.jp

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/

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

Manufacturer and Trading Firms

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/

C.I. KASEI CO., LTD.
1-18-1, Kyobashi, Chuo-ku, Tokyo 104-8321
TEL: 3-3535-4568 FAX: 3-3535-4542
E-mail: civil84@hn.cik.co.jp http://www.cik.co.jp/eng/

DENKI KAGAKU KOGYO KABUSHIKI KAISHA
Nihonbashi Mitsui Tower, 2-1-1, Nihonbashi-muromachi, Chuo-ku, Tokyo 103-8338
TEL: 3-5290-5465 FAX: 3-5290-5085
E-mail: dk010313@denka.co.jp http://www.denka.co.jp

FURUKAWA ROCK DRILL CO., LTD.
2-3-14, Nihonbashi-muromachi, Chuo-ku, Tokyo 103-0022
TEL: 3-3231-6982 FAX: 3-3231-6994
E-mail: jumbo@furudril.co.jp http://www.furukawarockdrill.co.jp/

Japan Tunnel Systems Corporation
2F, Ono-machi Building, 61-1 Ono-machi, Tsurumi-ku, Yokohama-shi, Kanagawa 230-0046
TEL: 45-521-8209 FAX:45-521-8248
E-mail: mitsutoshi_gotou@jtsc.ihigrp.ihi.co.jp
http://www.ihi.co.jp/jtst

Kayaku Japan Co., Ltd.
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 MECHATRONICS SYSTEMS, LTD.
2-16-5, Konan, Minato-ku, Tokyo 108-8215
TEL: 3-6716-4224 FAX: 3-6716-5833
E-mail: minoru_hokari@kbg.kobe.mhi.co.jp

Mitsui Miike Machinery Co., Ltd.
2-1-1, Nihonbashi-muromachi, Chuo-ku, Tokyo 103-0022
TEL: 3-3270-2006 FAX:3-3245-0203
E-mail: overseas@mitsuimiike.co.jp http://www.mitsuimiike.co.jp

Sandvik Mining and Construction Japan K.K.
6F, Kyoritsu Shin-Yokohama Bldg., 2-15-12, Shin-Yokohama, Kohoku-ku, Yokohama-shi, Kanagawa 222-0033
TEL: 45-478-0662 FAX: 45-478-0661
E-mail: koki.sakurai@sandvik.com
http://www.miningandconstruction.sandvik.com/jp

SOOKI Co., Ltd.
4-2-4, Kujou-Minami, Nishi-ku, Osaka-shi, Osaka 550-0025
TEL: 6-6586-1707 FAX:6-6586-1277
E-mail: system@sooki.co.jp http://www.sooki.co.jp/

VSL JAPAN CORPORATION
Tachibana Shinjuku Bldg., 3-2-26, Nishi-Shinjuku, Shinjuku-ku, Tokyo 160-0023
TEL: 3-3346-8913 FAX:3-3345-9153
E-mail: vsl@pop12.odn.ne.jp http://www.vsl-japan.co.jp

Memo