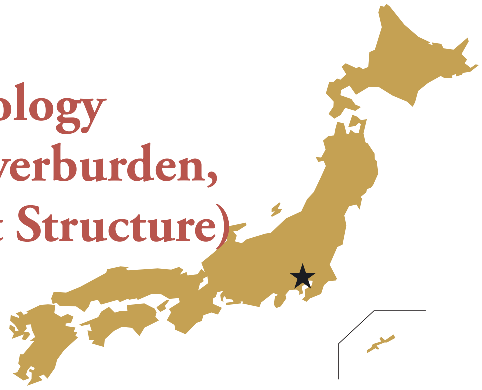
Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2014

JAPAN TUNNELLING ASSOCIATION

CONTENTS

Development of New Construction Technology for Under-railway Structure with Small Overburden, Using Ground Cutting JES (Joint Element Structure) Method



Takashi **SAITO** ▶ East Japan Railway Company

Overview of the construction site and project

The construction site of the underpass box culvert structure used the Ground-Cutting JES Method (referred to as "GC JES"). The site is 40 km north from central Tokyo. This work is a part of the construction of a loop expressway (Ken-O Expressway) and prefectural road below the Takasaki line of East Japan Railway Company (see Fig. 1).

The structure is 35.1 m long, 49.0 m wide and 8.9 m high, with four sections for roads. The section under the tracks is JES structure, and the sections on both sides are reinforced concrete structure. The minimum overburden is 1.4 m. The groundwater level is 4.0 m from the surface. The GC JES was used for 20 elements on the top of the box culvert.

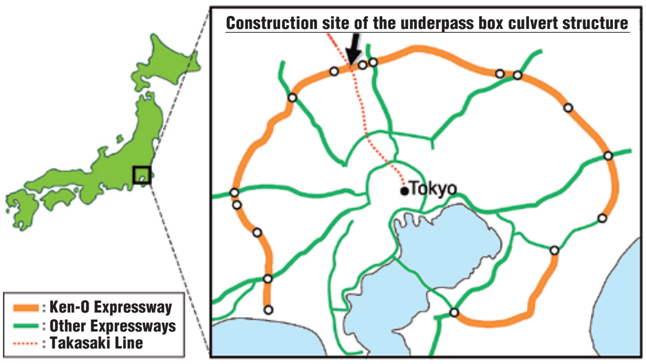


Fig. 1 Location of the construction site

Ground cutting system

The GC JES is provided with a box-shaped cutter unit on which an innovative cutting system is mounted. The wire saw on the upper part of the cutter unit cuts obstacles. This system minimizes displacement of the track caused by obstacles, enabling safe operation of trains. The motor in the cutter unit rotates the wire saw. Water is not used for the wire saw to prevent soil from loosening. (see Fig. 2).

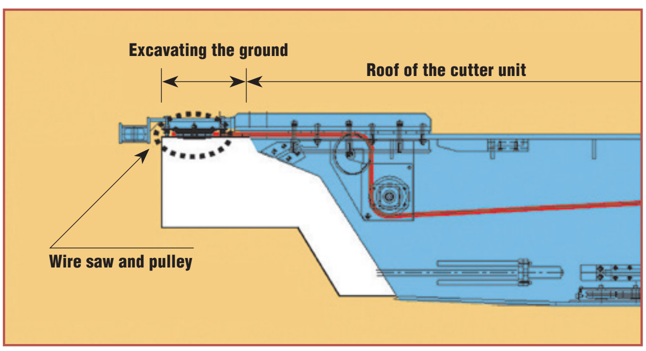


Fig. 2 Replacement of the ground cutting system

Construction record

Elements were pulled underground by the GC JES starting in September 2012 (see Fig. 3). To shorten the construction period, four groups worked simultaneously. The elements of the upper part of the box culvert structure were installed underground without serious accident by December 2012, as planned. During the work, the maximum vertical displacement increment was 4.4 mm, with no significant track displacement. During propulsion of the elements on the upper part of the box culvert, the objects broken by the cutter unit were stones (100 to 200 mm in diameter), utility wooden poles and concrete foundations. The cut objects were taken into the cutter unit and removed (see Fig. 4).

Fig. 3 Work in the starting shaft

Fig. 4 Obstacles cut and removed

Rapid Excavation Using SENS (the extruded concrete lining system with shield) of Unconsolidated Water-bearing Ground

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The Tsugaru Yomogita Tunnel is a Shinkansen double-track tunnel 6,190 m long on the Honshu side. The geology of the site is basically the Kanita formation mainly composed of unconsolidated water-bearing sand. Frequent soil collapses and quicksand are recorded in the results of previous tunneling in the Kanita formation. Therefore, the primary concerns of the project using conventional method were maintaining stability of the face and shortening the construction period. As a technique adequate for these requirements, the SENS (extruded concrete lining system with shield), a mechanized tunneling method, was selected, excellent in safety, ease of work and cost efficiency, having recorded successful results in previous projects in similar geological conditions.

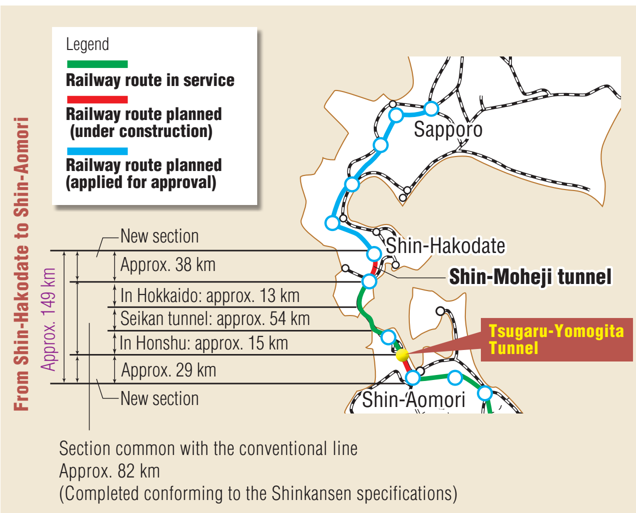


Fig. 1 Map of the Hokkaido Shinkansen

High speed excavation plan and results

To complete the section between Shin-Aomori and Shin-Hakodate (tentative name) by March 2016 within the specified construction time period, excavation was required to be performed at a speed much higher than the record when SENS was employed in the Sanbongihara Tunnel project on the Tohoku Shinkansen, that is, 110 m per month. In order to achieve this target, the performance of the primary lining concrete and mechanical equipment was improved as described below.

(1) Improvement of the performance of primary lining concrete

The primary lining concrete used in the SENS is pumped and filled into a narrow space simultaneously with advance of the shield machine, imposing the following requirements: 1) high fluidity for the concrete to be filled without compaction, 2) low viscosity to avoid segregation under high water pressure, 3) strength at an early stage for a large load bearing capability sufficiently developed at the time of removal of the inner mold, and 4) maintenance of freshness for a long time enabling intermittent pumping. (Fig. 1)

We developed a new mix proportion for low viscosity and good pumpability for the concrete to satisfy these requirements. By using this mixture that is able to maintain a required fluidity for long time, it was possible to decrease pump oil pressure, and to reduce cleaning frequency of the pumping pipes to once per week. In addition, by reformulating air-entraining superplasticizer and early strengthening agent, stable concrete properties were maintained, not dependent on seasonal temperature change.

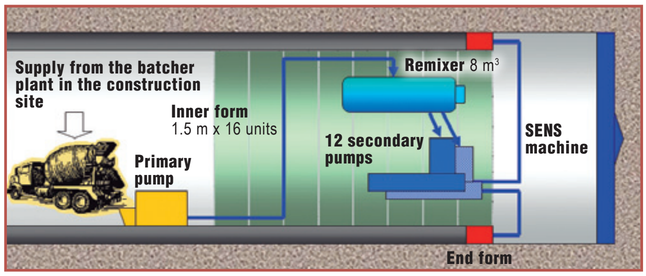


Fig. 2 SENS's primary concrete placement equipment

(2) Improvements of the mechanical equipment

- The number of secondary concrete pumps was increased (from 6 to 12 pumps).
- Changes to the inner form width (from 1.2 m to 1.5 m), insertion in the axial direction of the inner form, and a change in machine structure, aimed to achieve more efficient and safe assembly and disassembly of the inner form.

Results of the improvements for high-speed excavation

The improvements described above remarkably improve construction performance. At construction cost similar to that of conventional tunneling method in unconsolidated water bearing ground. It was possible to excavate at a high speed comparable with the shield tunneling, with a monthly average advance of 190 m except for bit replacement in the intermediate shaft, and the maximum monthly advance being 367.5 m. (Photo 1)

Photo 1 SENS's breakthrough to the portal

Construction of a Large Section Tunnel with Small Overburden by the Central Diaphragm Method

- Yagiyama Tunnel on the Sendai City Subway Tozai Line -

Hiroaki **YOSHINO** ▶ Tokyo Regional Bureau, Railway Construction Headquartes, Japan Railway Construction, Transport and Technology Agency(JRTT)

The Sendai City Subway Tozai (east-west) Line is 13.9 km, linking east and west areas of the city. It is now under construction to be opened to service in 2015 for the purpose of alleviating traffic congestion and improving accessibility to the central district of the city. The Yagiyama Tunnel on this line is 648.5 m long, constructed by the conventional method. Since the segment 73 m long from the start point accommodates station facilities such as platforms, the excavation cross-section is large, 181 m^2 . The construction conditions for this segment are very difficult: asymmetrically pressured topography with a retaining wall about 5 m high just above the tunnel, a city road on one side of the tunnel, average overburden is about 9 m, geology of soft rock of the Neogene, and weak strata with N value of about 20 at the tunnel crown and above it. (Fig. 1)

Construction plan

Before construction of the Yagiyama Tunnel, large-section tunnels have been constructed by two methods in the subway Tozai Line project, center diaphragm (CD) method and multi-stage bench method. Considering the construction conditions at the site and the record of the preceding tunnels, the center diaphragm (CD) method was selected, because it stabilizes the face, minimizes displacement and ensures safety. On the other hand, considering the asymmetrically pressured topography, surface settlement was predicted by FEM analysis. As a result, in order to minimize impact on the ground just above the tunnel, it would be preferable to excavate first a small section on the retaining wall side where there are large earth pressures in order to stabilize the face and tunnel during excavation. In addition, long steel pipe forepiling and early high strength shotcrete (developed strength 3.0 N/mm^2 or more at the age of 10 minutes) were used to stabilize ground as early as possible and limit displacement. The support (steel rib) pattern is shown in Fig. 2

Results

The tunnel was constructed by careful measurements, and completed without accidents in mid June 2012. The surface settlement was 18 mm at the tunnel center and 29 mm at the retaining wall foundation (R1), one meter right from the center. Displacement finished at around 60 to 70% of the FEM analytical value. Surface displacement was not observed at a location where the face was approximately 1D to 2D (D = tunnel diameter) from the measurement point. As shown by this fact, even under severer construction conditions, displacement could be controlled in the early stages.

It was revealed that axial force remained in the center diaphragm supports (steel ribs) until the diaphragm wall was removed, and after removal, part of the axial force (about 70% in this case) was redistributed as axial force in the arch supports.

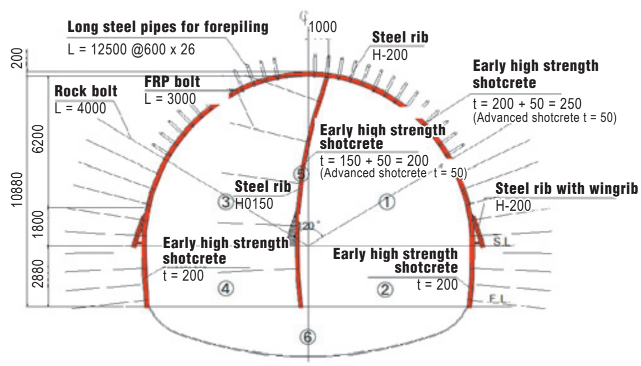
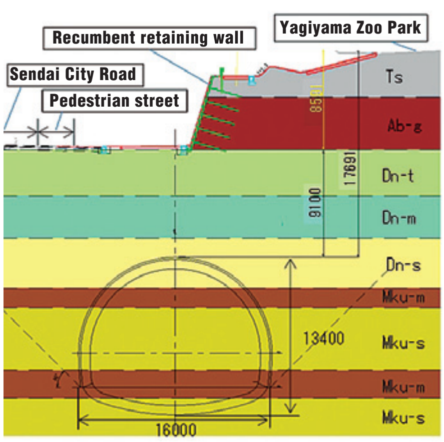


Fig. 2 Support pattern



Age		Formation	Code	Name of bed
Quaternary	Holocene	Top soil-mound	Ts	clay w. sandstone, sandstone w. clay, siltstone with sandstone
	Pleistocene	Aobayama formation	Ab-lm	loam, clay w. sand
			Ab-c	tuffaceous clay, organic clay
			Ab-g	sandstone, sandstone with clay
Neogene tertiary	Pliocene	Dainenji formation	Dn-m	sandstone, siltstone conglomerate
			Dn-t	tuff, tuffaceous siltstone
			Dn-s	sandstone, tuffaceous sandstone
		Mukaiyama formation: Upper Mukaiyama layer	Mku-m	mudstone, siltstone, tuffaceous siltstone
			Mku-t	tuff, pumiceous sandstone
			Mku-s	sandstone, tuffaceous sandstone
		Mukaiyama formation: Hirosegawa tuff layer	Mkt	pumice tuff, tuffaceous sandstone

Fig. 1 Geological section of the large-section segment of the asymmetrically pressured topography

Photo 1 Central diaphragm (CD) method

Development of the Flat Insulated Lining Method (FILM) for High Quality Tunnel Lining

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Kyushu Shinkansen Construction Bureau,
Railway Construction Headquarters,
Japan Railway Construction, Transport and Technology Agency (JRTT)

We have developed a novel lining technique "Flat Insulated Lining Method (FILM)." The FILM eliminates unevenness on the back surface of the lining, by injecting filler into the void between waterproofing membrane and shotcrete, thereby stretching the waterproofing membrane flat. This is an excellent technique for high quality and durable lining concrete. This article reports the trial application of the FILM in the project of the Tawarazaka Tunnel (double-track tunnel, 5,675 m long) on the Kyushu Shinkansen line (west Kyushu route).

Overview of the FILM

The design philosophy of mountain tunneling in Japan requires that the lining concrete should furnish functions such as waterproofing and fire resistance while the tunnel is in service. Although various measures and improvements both in design and construction have been made, cracks and water leaks frequently occur in the lining, which are deemed to be mainly attributable to defective waterproofing membrane caused by uneven surface of the back of the lining. The FILM injects solidifying filler into the void between waterproofing membrane installed on the specific movable formwork and the support, so that the membrane and support are integrated, resulting in the membrane being evenly stretched (Fig. 2, Photo 1). This technique places high quality lining concrete with no unevenness on the back.

Features of the FILM

With the FILM, the waterproofing membrane is installed mechanically and systematically, presenting the following advantages in construction.

-Manual works are significantly reduced, thereby improving work safety.

-Mechanization enables a long-span waterproofing membrane to be installed, reducing welding in the construction site and loss of waterproofing membrane.

-Requires no expertise for evaluating uneven shotcrete surface, or for determining margin of waterproofing membrane.

-The placement volume of lining concrete becomes almost constant, resulting in easier and clearer management of construction.

Prospects

In Europe, a membrane 3 to 5 mm thick is used for some watertight tunnels for the purpose of preserving the water environment. In rapidly developing countries such as China, lack of skilled manpower is a serious problem and mechanized construction technologies are strongly demanded to secure quality and safety.

Under these circumstances, the FILM provides various attractive advantages. Through further research and development, the FILM will contribute to progress of tunnel construction technology in the world.

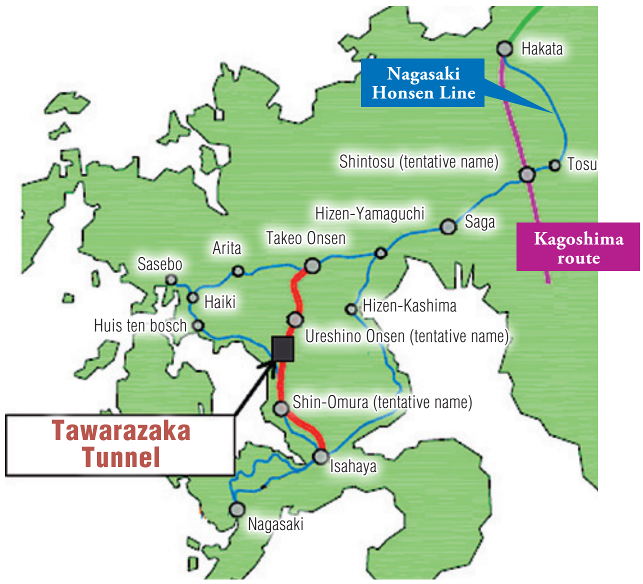


Fig. 1 Overview of the Kyushu Shinkansen (West Kyushu route)

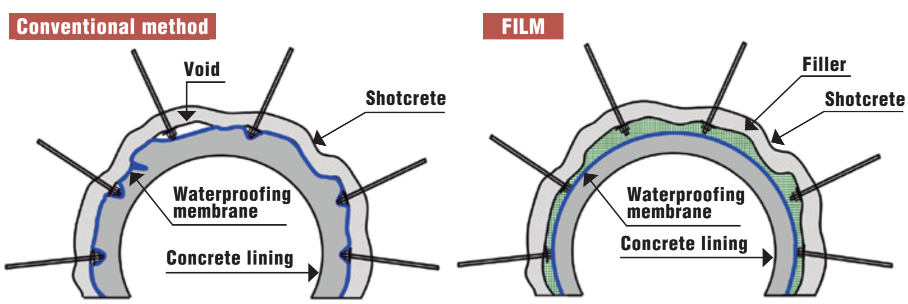


Fig. 2 Concepts of conventional lining method and FILM

Photo 1 Installation of waterproofing membrane

Tunneling with Effective Drainage in a Collapsed Zone by Landslide

- Shin-Moheji Tunnel on the Hokkaido Shinkansen Line -

Yoshiaki **TANAKA** ▸ Hokkaido Shinkansen Construction Bureau, Railway Construction Headquarters, Japan Railway Construction, Transport and Technology Agency (JRTT)

The Hokkaido Shinkansen is a railway line about 360 km long between Shin-Aomori and Sapporo. The section of this line between Shin-Aomori and Shin-Hakodate (tentative name) approximately 149 km long is under construction, planned to be completed in 2015. In 82 km of this section including the Seikan tunnel (53,850 m), the longest undersea tunnel in the world, structures conforming to the Shinkansen specifications have already been completed. The new construction portion is about 67 km long (29 km on the Honshu side, 38 km on the Hokkaido side).

The Shin-Moheji tunnel is a Shikansen double-track tunnel, 3,345 m long, and located on the Hokkaido side (Fig.1). It was constructed by conventional method, with short bench cut, mechanically excavated by a road header.

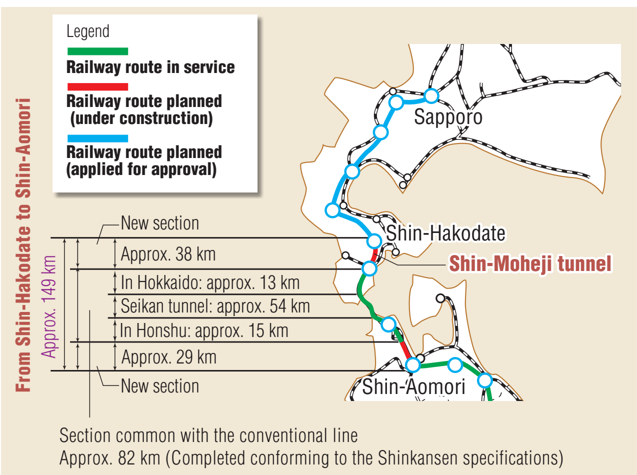


Fig. 1 Map of the Hokkaido Shinkansen

Collapsed zone and groundwater level

One of the characteristics of this tunnel is that it passes below a collapsed zone formed by landslide, at around 500 m from the west portal. The collapsed zone has a complex geological structure, presenting progressive loosening caused by weathering. Another challenge of this project was that, around the collapsed zone, the groundwater level is at 30 to 40 m above the tunnel crown. Because of these reasons, we determined to take measures to prevent sudden groundwater inflow and soil discharge during tunneling below the collapsed zone, and planned effective measures.

Measures for groundwater

To select the most effective measures in the collapsed zone, we conducted an additional geological survey to determine precise groundwater levels and geology. We accurately located an aquifer and obtained detailed geological data (Fig. 2). Since the strata of the collapsed zone were proved to be very permeable, we planned drainage boring from inside the tunnel from the view point of efficacy and economic performance. Casing pipes were installed in the holes bored by rotary percussion. As the face advanced, ten bores for drainage were constructed at the assumed location of the aquifer. (Fig. 3)

The drainage boring reached the aquifer and one of the bores recorded a peak water in flow of 1,200 liters/min for drainage. The groundwater level lowered successfully to near the old landslide plane. Consequently, there was almost no water inflow through the face during excavation, and safely passed through below the collapse zone.

Thanks to this effective groundwater measures based on in-depth surveys, this tunneling project was successfully performed, satisfying both safety and economic requirements, without resorting to surplus auxiliary stabilizing methods. Breakthrough was achieved in March 2012.

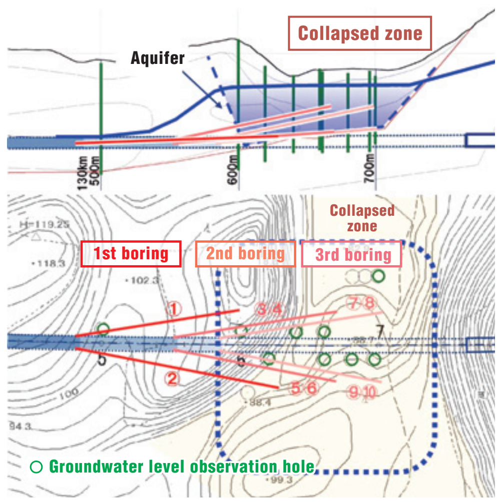


Fig. 3 Planning diagram of drainage boring

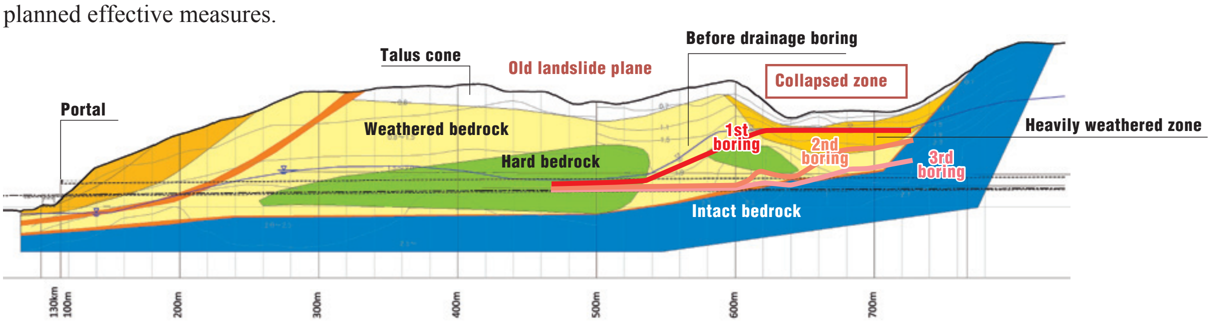


Fig. 2 Longitudinal profile of the Shin-Moheji Tunnel

Construction of Subway Linking Lines by the Muddy Soil Pressure Balanced Shield Method of Combined Circular Section

- Construction of Link Lines on the Tokyo Metro Yurakucho/Fukutoshin Lines -

Takashi **HIRANO** ▶ Design Section Assistant Manager, Renovation & Construction Department, Tokyo Metro Co., Ltd.

Tokyo Metro Co., Ltd. is constructing link lines (A and B) between Kotake-mukaihara and Senkawa Stations where Yurakucho line and Fukutoshin line join together and branch currently with the train tracks intersecting on the same level. The link lines will ensure more reliable transport on these lines, by eliminating these level intersections that tend to disrupt the train operation schedule, causing delays. (Fig. 1)
Since the district is a quiet residential area with rich greenery, the tunnel alignment and construction zone were determined with the main considerations given to the following three points.
1) Alignment to locate the construction zone beneath roads.
2) Structure and construction methods that minimize impact on the subway lines in service.
3) Structure and construction method that curb adverse effect on the surface.

As a result, the cut and cover tunneling method was selected for the branching section on each end of the construction zone and the single-track tunneling by a shield method of combined circular section for the intermediate zone. This shield tunneling technique minimizes adverse effects on the surface, effectively utilizing the underground space and alleviating environmental impact by reducing excavation volume.

Sectional geometry

The sectional geometry along the tunnel was required to be designed suitably for the following goals.

1) To keep a sufficient distance from private land and from the existing tunnels of subways in service.
2) To curb environmental impact by reducing the sectional area.
Consequently, the selected sectional geometry is vertically oblong, combined of three different curve radii (R1 = 7800, R2 = 5500, R3 = 2000 mm).

With this sectional geometry, enough area in tunnel for subway operation could be secured, while reducing the sectional area by 10% compared with the circular section. Among the three curve radii, the arcs of the lateral and top/bottom sections (R1 and R2) were determined first, considering the required cavity, and lastly the arc (R3) was determined, whose center is the intersection of the other two curve radii.
The segments (six pieces per ring) are made of reinforced concrete, 300 mm thick and 1500 mm wide (Fig.2).

2 Shield machine

The muddy soil pressure balanced shield method was selected, because its trailing gear is compact, suitable for the construction environment with a narrow work yard, and has been used successfully to complete non-circular section tunneling many times.
The outer dimension of the machine is 5700 mm wide and 6800 mm high, with each spoke of the cutter head provided with an expansion type cutter. Its structure is simple and sturdy, enabling excavation of the combined-circular section by extending and shrinking the expansion type cutter following the main cutter rotation (Fig. 3).

Construction

Since simultaneous construction of A and B lines would significantly affect the traffic on the surface, each line was planned to be constructed at separate times. A line was opened to service in March 2013. For completion of B line, preparation will consist of tuning up the disassembled cutter head, muck removal system, erector, shield jacks, and shape-retention unit, etc. of the shield machine will be made at a plant.

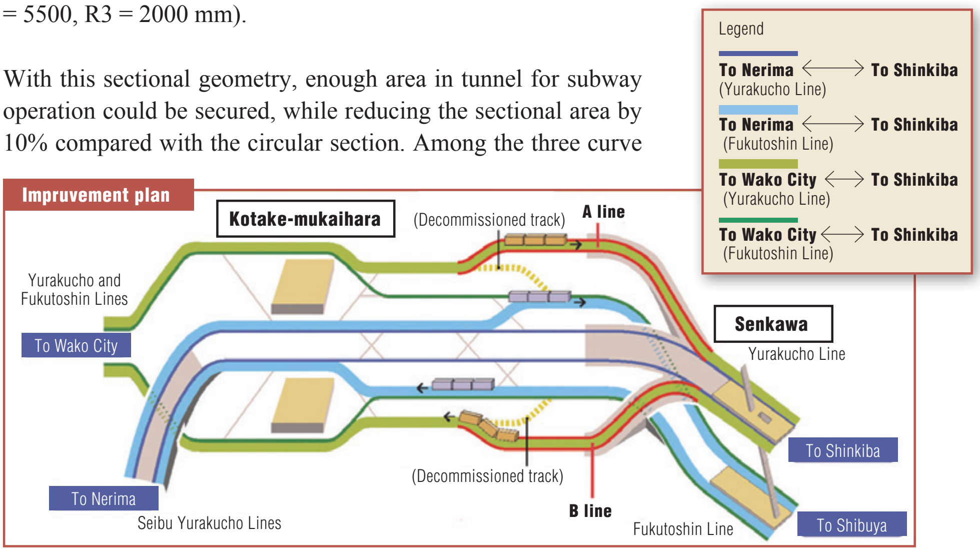


Fig. 1 Schematic diagram of the Subway linking lines

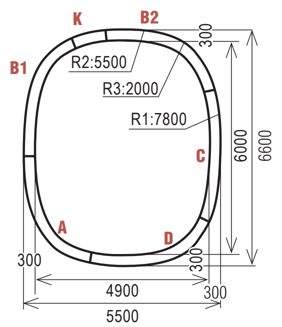


Fig. 2 Combined-circular shield tunnel section (single track)

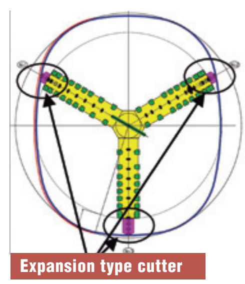
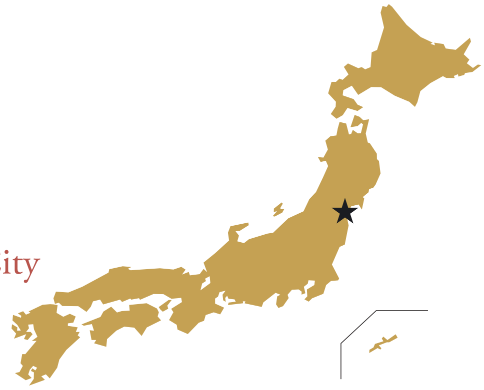


Fig. 3 Details of the shield machine

Three-dimensionally Curved Shield Tunneling Project

- Shield Tunneling in the Ichiban-cho Section on the Sendai City Subway Tozai Line -

Makoto **Sugimoto** ▸ Manager, Kajima Corporation ,Tohoku Branch



Overview of the Sendai City Subway Tozai (east-west) line and the construction in the Ichiban-cho section

The Tozai (east-west) line supports development of the Sensai district in the 21st century. The Tozai line has 13 stations, with length of approximately 14.4 km. Of the Tozai line, we reported on the Aobayama Tunnel and Kameoka Tunnel constructed by the conventional method. We discuss here the Higashi Niban-cho Tunnel connecting the station of Sendai, the largest city in the Tohoku district, and Ichiban-cho, a busy downtown area. This tunnel is composed of twin single-track tubes, constructed by the high density foaming shield tunneling method (two tubes 568.3 m long, outer diameter of the segment ring 5,400 mm). This project is featured by the alignment of twin tubes of S-shaped "sharp curve" with the minimum curve radius of 105 m and "large gradient" of 4% in the maximum longitudinal inclination, that is to say, one of the most challenging tunneling projects in Japan. The main structures in the vicinity of the tunnel are a commercial building (vertical distance from the tunnel: 5.3 m) and a common duct and NTT tunnel (vertical distance: 10.8 m), and an underground road.

Overview of shield tunneling

(1) Geology

The geology of the tunneling site is mainly composed of mudstone, with intercalated sand stone and tuff strata. The N value is 50 or more.

(2) Alignment

The shield machine leaving the Ichiban-cho station, in the horizontal view, passes a crothoid curve, and goes to a right-hand curve of 105 m in radius, while, in the vertical view, goes down along an arc of 4,000 m in radius to the largest gradient of 4%. Then, the machine passing through a short straight section goes to a left-hand curve of 105 m radius, while, in the vertical view, follows an arc of 4,000 m in radius whose gradient gradually diminishes and arrives at the Sendai station.

(3) Segments

Two types of segments were used. Segments for the general section are made of reinforced concrete (beam height 280 mm, width 1,200 mm), and those for sharp curve and heavy load sections are composite segments (beam height 200 mm, width 800 mm).

Impacts of the shield tunneling

The shield machine leaving the Ichiban-cho station in August 2012, starting on the west-bound line, and arrived at the shaft at the Sendai station in January 2013. Then, the machine made a U turn in the shaft. At the end of February 2013, the machine started on the east-bound line and arrived at the Ichiban-cho station in July. The machine was transported into the arrival shaft at the Sendai station, inserted and moved slightly horizontally, and, at the starting position of the east-bound line, turned 180 degrees. It was possible to restart in a short period, about one month. Although the project was difficult with the three-dimensional curved alignment, the direction changing horizontally and vertically at the same time, the quality of the tunnel completed was satisfactory, with almost no cracking of the segments or damage at their edges, or water inflow.

Photo 1 S-shaped curve on the west-bound line

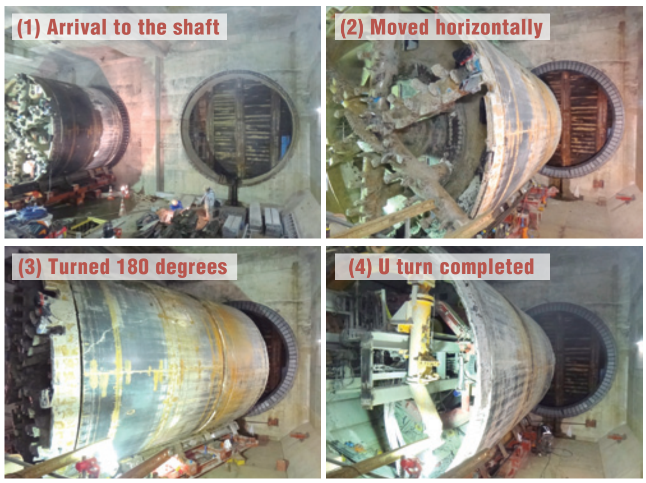


Photo 2 U turn process of the machine

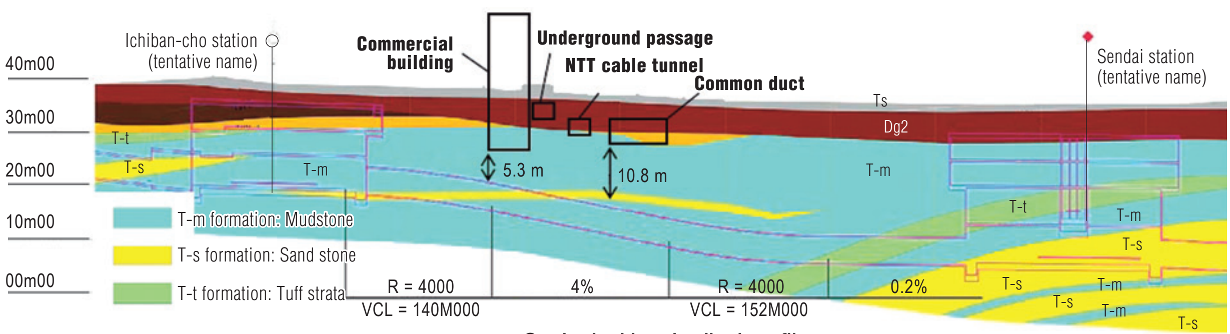


Fig. 1 Geological longitudinal profile

Completion of Tunnels on the Yamanashi Maglev Test Line, Chuo Shinkansen

Takashi **WATANABE** ▸ Section Manager of Chuo Shinkansen Promotion Division, Central Japan Railway Company

The Central Japan Railway Company is almost ready to start constructing the Chuo Shinkansen using the Superconducting Maglev system with operating speed of 500 km/h, not only as a far-reaching measure to counter future aging of the Tokaido Shinkansen linking the largest three cities "Tokyo-Nagoya-Osaka", but as a safeguard for future large-scale disasters like huge earthquakes.

The first step of the project is to build a line between Tokyo and Nagoya (about 286 km) (Fig. 1), including tunnels about 246 km long in total (about 86% of the entire line).

We have already completed the construction of the Maglev test line spanning 42.8 km. It will serve as a part of the Chuo Shinkansen in the phase of commercial operation.

Construction of tunnels on the Yamanashi Maglev Test Line

In April 1997, initial test runs began in the priority section (18.4 km) of the Yamanashi Maglev Test Line. In May 2008, we started to extend the line to 42.8 km, including newly designed extension line of 24.4 km, and to upgrade facilities of the priority section (Fig. 2).

In March 2012, breakthrough of all the tunnels was achieved. After installation of equipment and elaborate verification, we finally resumed the running test on the entire test line over 42.8 km with the Series L0, the first generation of vehicles based on the specifications for commercial operation in August 2013. For the new test line, we committed ourselves to bringing down costs of construction, operation and maintenance of commercial line as well as improving the Superconducting Maglev technology.

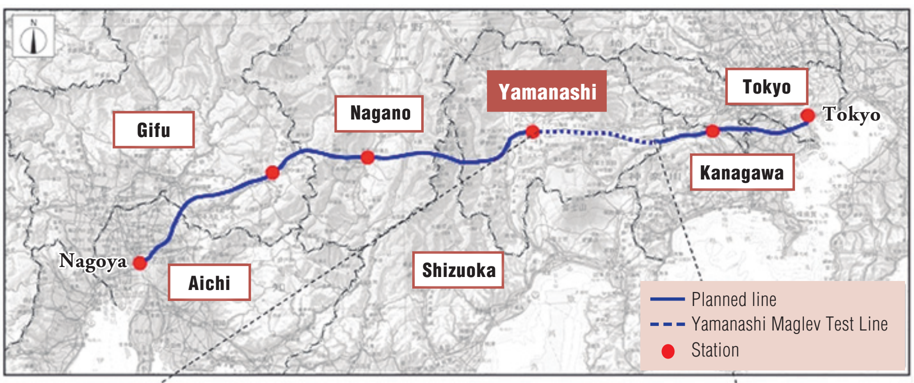


Fig. 1 Planned line between Tokyo and Nagoya, Chuo Shinkansen

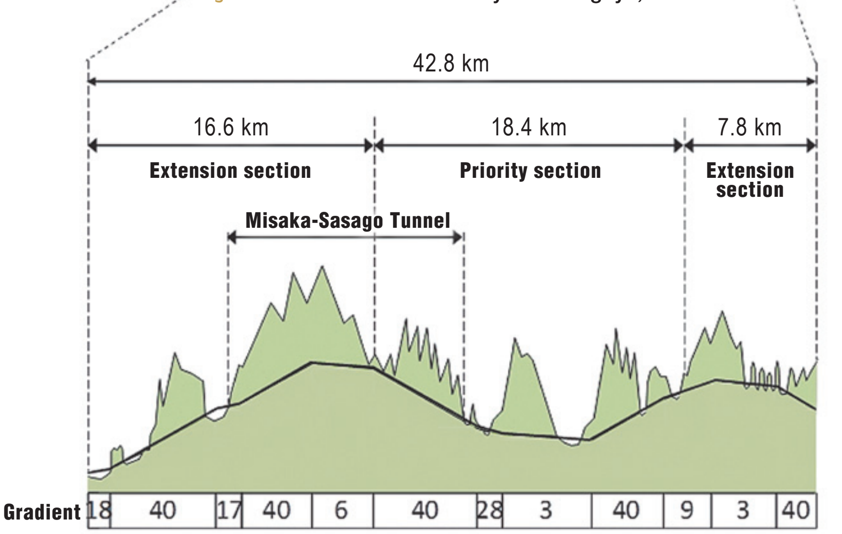


Fig. 2 Profile of the Yamanashi Maglev Test Line

The extended section is 19.1 km long and contains ten tunnels. The Misaka-Sasago Tunnel (14.6 km), which is located between extension and priority sections, is the longest on the test line. The effective sectional area of the cavity of the Superconducting Maglev line tunnels is 74 m² (Fig. 3). The lining thickness in the general ground conditions is at least 300 mm. The standard lining concrete is cast-in-place plain concrete, whose design strength is 18 N/mm². In the sections such as portals that are lined with concrete with double reinforcing-bar, the design strength is 24 N/mm². In the sections with small overburden, fiber reinforced concrete was used.

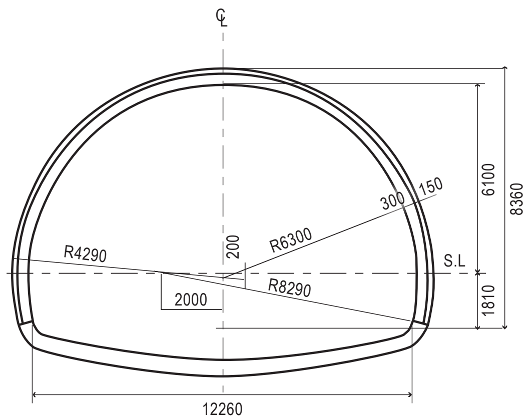
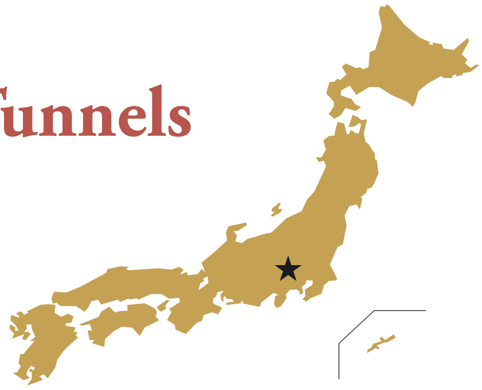


Fig. 3 Standard cross section of tunnel

Spherical Face Excavation for Tunnels

- Hachinoshiri Tunnel on the Chubu Odan Expressway -



Jun **SATO** ▶ Deputy Director, Minami-Alps Construction Office,
Central Nippon Expressway Co., Ltd.

The Hachinoshiri Tunnel, 2,469 m long, is located between Rokugo Interchange and Masuho Interchange north-west of Mt. Fuji, at the end of the Chubu Odan Expressway. The overburden thickness is 150 m, and the geology is composed of mudstone and basalt, and in the center there is weak mudstone, whose competence factor is less than unity. This mudstone section is currently being excavated.

Spherical face

This approach is aimed at reduced use of additional stabilizing methods by providing the face with a spherical shape for better stability (Fig.1). Numerical analysis verified that the extrusion of the spherical face is reduced by 20%, which proves the stabilizing effect. However, with this method the face at the crown becomes overhung, giving a presumption that spherical face excavation is prone to collapse. The spherical face method, therefore, has not been used for actual projects up to now. In the Hachinoshiri Tunnel, the full face was excavated with a large roadheader to quickly form a circular section that features high stability and reduce access time of workers. This was the first attempt in Japan at excavating a large section with a spherical face.

First, the target spherical shape was set, and then the face shape after excavation was measured in 22 sections with a 3D scanner. Based on the results of this study, the standard spherical shape was determined (Fig. 2).

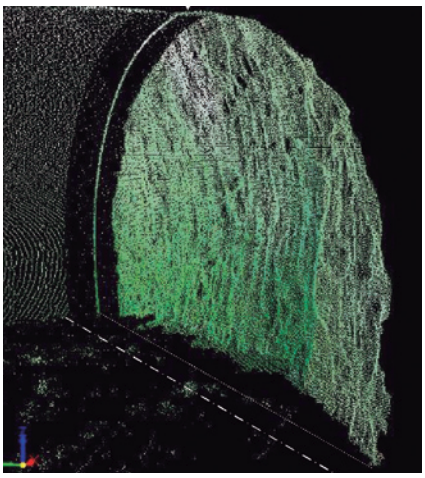


Fig. 1 Spherical face measured with a 3D scanner

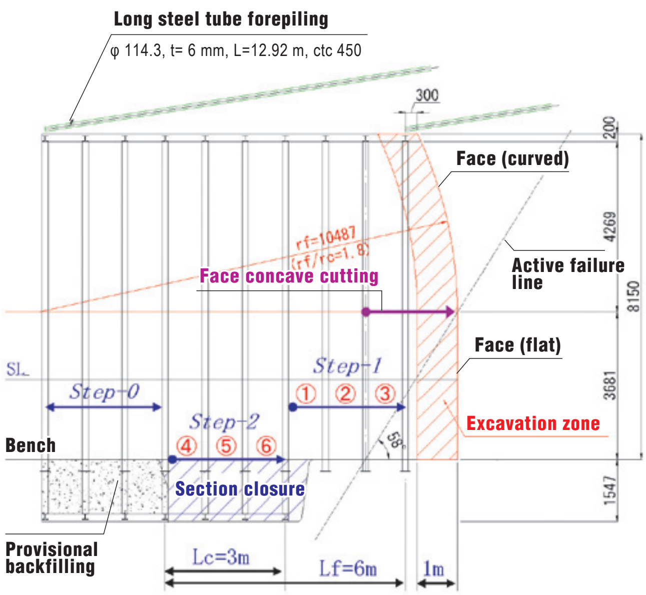


Fig. 2 Standard spherical shape and sequence of early section closure

Excavation of weak mudstone ground by spherical face method and early full-face section closure

Currently, the weak mudstone section in the center of the tunnel is being excavated with the spherical face method and early full-face section closure. By the spherical face approach, it is possible to create a space in the bench for excavation, to store the muck temporarily and to enlarge the work yard, thus contributing to work efficiency.

Even in ground where large deformations are anticipated, a spherical face and early section closure by large-section cutting make it possible to build ring structures of supports, curbing displacements, thereby stabilizing ground.

Evaluation of a spherical face

The results of construction show that making the face spherical is an excellent solution for workability and safety.

- By working a certain distance away from the face, they can do their jobs feeling free from oppression.
-Excavation at the foot of steel arch supports is easy, facilitating erection.
-Face closure is possible using invert supports.
-Face stability is significantly improved by shotcreting about 5 cm on the face.

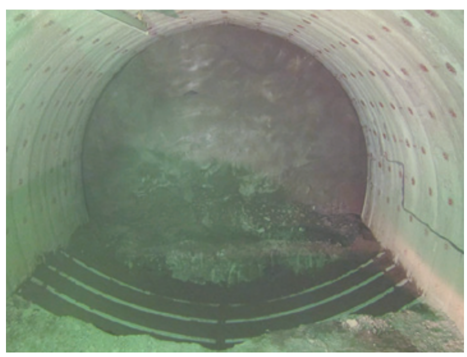


Photo 1 Early full-face section closure

Tunneling with Measures for Minimizing Adverse Effects on Groundwater Flow

- Construction of the Minoo Tunnel on the Shinmeishin Expressway -

Manabu **YAMASHITA** ▸ Chief
Shinmeishin Osaka Nishi Construction Office, Kansai Regional Branch,
West Nippon Expressway Company Limited

The Minoo Tunnel is on the Shinmeishin Expressway (between Nagoya and Kobe), an access-controlled road, located in eastern Osaka prefecture, approximately 5 km long, with east-bound and west-bound routes having two lanes each. This tunnel passes under a river (Katsuoji-gawa) at 1 km from the east portal (overburden about 20 m). The Katsuoji-gawa area is located near the Minoo quasi-national park, featuring rich nature and abundant water resources used by residents for agriculture.

Technology for preserving the environment including groundwater

Where the tunnel passes under the Katsuoji-gawa, the overburden is small and there are concentrated fracture zones. There was, therefore, a possibility that groundwater near the surface and river water would infiltrate the tunnel. To cope with this problem, we analyzed the presumed infiltration flows three-dimensionally, and designed a watertight (WT) configuration for the tunnel structure. The water pressure acting on the WT zone is 1.0 MPa. In addition, using hydrogeological information obtained during construction, effects on the groundwater were assessed, thereby conducting “groundwater-information-oriented construction” for effectively preserving the hydrological environment.

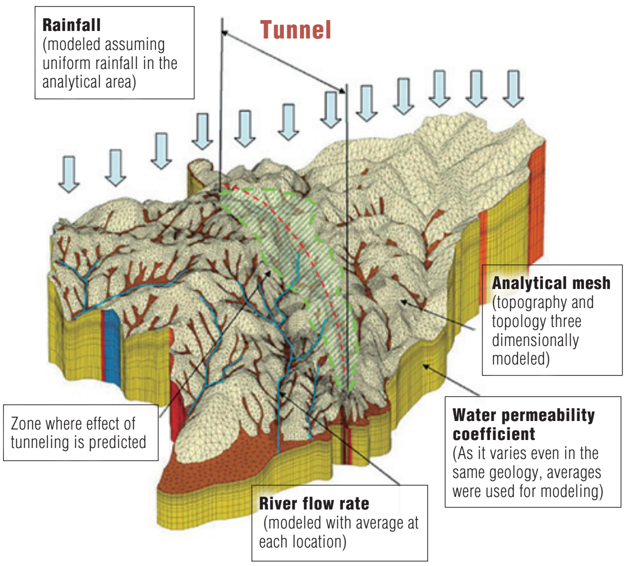


Fig. 1 Schema of the 3D infiltration analytical model

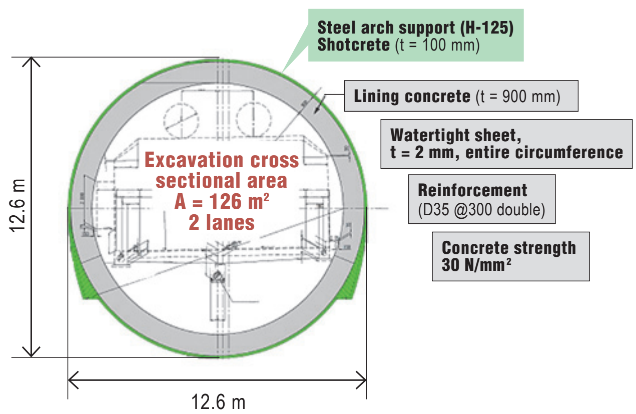


Fig. 2 Configuration of the WT zone
WT zone Water pressure resistance of the lining

Specific surveys and work practices of the groundwater-information-oriented construction

Referring to the results of the boring survey, electric prospecting, elastic wave exploration, geological survey, and river head (uppermost stream) survey, the geological structure and groundwater levels in the WT zone were assumed in a manner to cover all of the supposed plural fracture zones. The WT zone was set extending about 12 m, at both ends, into the solid intact rock area with a water permeability coefficient of 2.7 x 10^{-7} (m/sec) or under, in order to prevent groundwater from flowing out.

To avoid lowering of the rate of river flow during excavation, the river flow was bypassed and a drainage system was built to return the inflow into the tunnel to the river. This system is composed of a vertical bore connecting to the surface, and a drift connecting the vertical bore and the main tunnel.

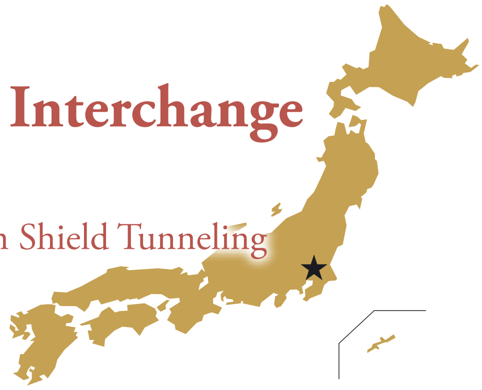
In the tunnel, an approx 1,000 m survey hole was bored to validate the effectiveness of the WT zone. In the boring survey, zone water inflow rate analysis, geological analysis, boring energy analysis and borehole RQD analysis were performed, and the water permeability coefficient around the tunneling face was measured.

On the surface, observation wells were bored to determine the effects of tunneling on groundwater by continually monitoring groundwater level and river flow rate. The observation results were checked in real time using smartphones. Moreover, the deep water pressure was monitored around the tunnel for a long period, to use the results for the study and design of the lining structure.

Photo 1 River flow rate monitoring

Construction of the Yatsu-Funabashi Interchange on the Higashi-Kanto Expressway

- Construction of a Ramp Tunnel by the Divided Large-section Shield Tunneling in a Landfill below a Heavily Traveled Road -



Kazuhiro **SHINO** ▸ Chiba Construction Office, East Nippon Expressway Co., Ltd.

The Yatsu-Funabashi Interchange on the Higashi-Kanto Expressway is a half-interchange under construction to alleviate chronic traffic congestion in the district.

The off-ramp tunnel of this interchange has a sharp curve (R = 50 m), an overburden of about 3 m, and runs just below the Higashi-Kanto Expressway heavily traveled with an average of more than 10 thousand vehicles per day. Since the site is located in a reclaimed tidal flat, debris of old revetment was removed during tunneling.

These adverse conditions were overcome by effective utilization of an ingenious shield tunneling method and ground improvement. Thus, the Yatsu-Funabashi Interchange was completed without affecting traffic on the Higashi-Kanto Expressway and opened to service in September 2013.

Main features of the construction

(1) Shield tunneling

As for the geology, the top layer is reclaimed land and the tunneling section is mostly alluvial, where the face tends to be unstable. In addition, the site is surrounded by a tidal flat where the groundwater level is high. To cope with these difficult conditions, the closed type, high-density slurry shield method was selected (Photo 1). The tunneling sequence was as follows. First, the tunnel structure was divided into six sub-sections. Then shield machine was used to construct each sub-section tunnel (Fig. 1), water seal chemical was grouted, and the concrete structure was constructed. After that, the ground surrounded by the six sub-section tunnels was excavated to complete the ramp tunnel.

Photo 1 Closed type high, density slurry shield method

(2) Removal of debris in reclaimed land during tunneling

When constructing the upper two of the six sub-section tunnels, the shield machine passed through the reclaimed land that contained debris. Therefore, to advance the shield, it was necessary to remove the debris (Photo 2). To make this job possible, the shield machine was modified into an open type (Photo 3). The cutting head of the machine was made to remain open during excavation. Therefore, in order to stabilize the face during excavation and to minimize impact of excavation on the road near the intersecting tunnel, ground improvement and chemical grouting were also performed (Fig. 1).

Photo 2 Debris remaining in the reclaimed ground

Photo 3 Open type shield machine

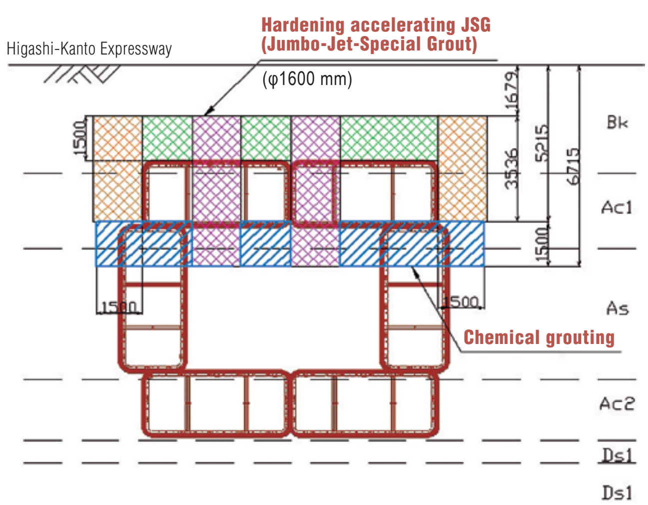


Fig. 1 Sub-section shield tunneling and ground improvement

New Enlargement Technique for Shield Tunnels

- Yokohama Circular Northern Route Project -

Kiyoshi **KASUGA** ▸ Deputy Manager
Design Division, Kanagawa Construction Bureau,
Metropolitan Expressway Co., Ltd.

The Yokohama Circular Northern Route is an expressway with length of approximately 8.2 km. 70% of the total length (about 5.9 km) is underground, including a 5.5 km shield tunnel with outer diameter of 12.3 m.

There are four ramps for the entrances and exits around the middle of shield tunnel section. The main shield tunnel is enlarged to connect with the ramp. Construction for the enlargement is performed in the main shield tunnel, because the surface above these ramps is a residential area.

Geology

The overburden of the enlargement area is 28 to 54 m. The geology of the ground to be excavated is mainly composed of hard mudstone (Km) and sandy mudstone (Kms) with uniaxial compressive strength 1,000 kN/m^2 or more. The Km and Kms layers contain sand and sandstone (Ks) layers with N value 50 or more.

The maximum water pressure of the Ks layer is 0.5 MPa in the enlargement area and the coefficient of uniformity of Ks is relatively low (around 6), so quicksand could occur if groundwater is discharged through the layer.

There is also the possibility that the Ks layer may be hydraulically connected with the alluvial stratum above. Consolidation settlement of the alluvial stratum would be induced if the groundwater level drops.

New technique for enlargement of shield tunnels

If only geology is taken into consideration, the Convergence Confinement method could be adopted to enlarge the main shield tunnel. However, because the utilization of the surface must also be considered, a technique for ensuring water tightness was selected to reduce impact on the surrounding ground.The new technique for enlarging shield tunnels is shown in Fig. 2.

At first, chemical grouting in the main shield tunnel is carried out at the front, the end, and several points in the enlargement area to make a water cut-off wall.

Then, at the front of enlargement area, an enlargement shield tunnel with rectangular section (Height: 2.8 m, Width: 11.0 m) around the main tunnel is constructed to make space for the steel pipe-roofing. Even though the enlargement shield tunnel section is chemically grouted for water tightness, the Earth Pressure Balance tunneling system is adopted to prevent potential flooding and make mucking efficient.

After the enlargement shield tunnel is completed, steel pipe-roofing (1.2 m in diameter) is placed in the longitudinal direction and covers the enlargement area. Then the chemical grouting from the inside of the steel pipes is carried out between the pipes.

Thus the enlargement area is enclosed by the main shield tunnel, pipe-roofing, and chemical grouted zones (at the front, the end of the enlargement area and between the pipes) to ensure water tightness during enlargement.

After constructing the watertight cover, the main shield tunnel segment is opened over a width of 4.0 m in the tunnel longitudinal direction, and the ground is excavated within the pipe-roofed zone. In the excavated section to be enlarged, the permanent lining concrete is placed. After the required strength of the concrete is achieved, the next adjacent block is excavated. Since the pipe-roofing is always supported by the permanent structure or unexcavated ground, the rigidity of the pipes make it possible to reduce the movement of the surrounding ground.

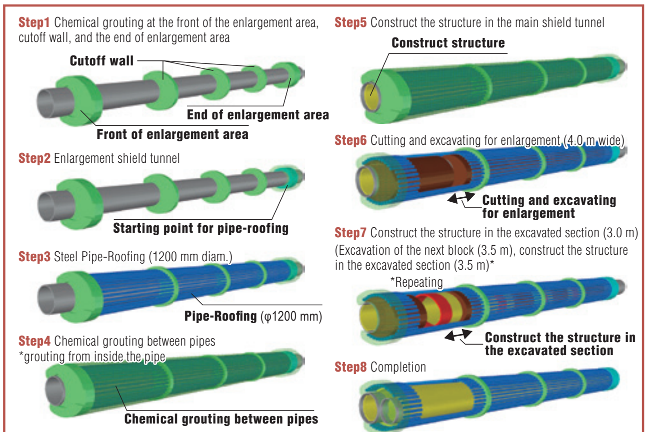
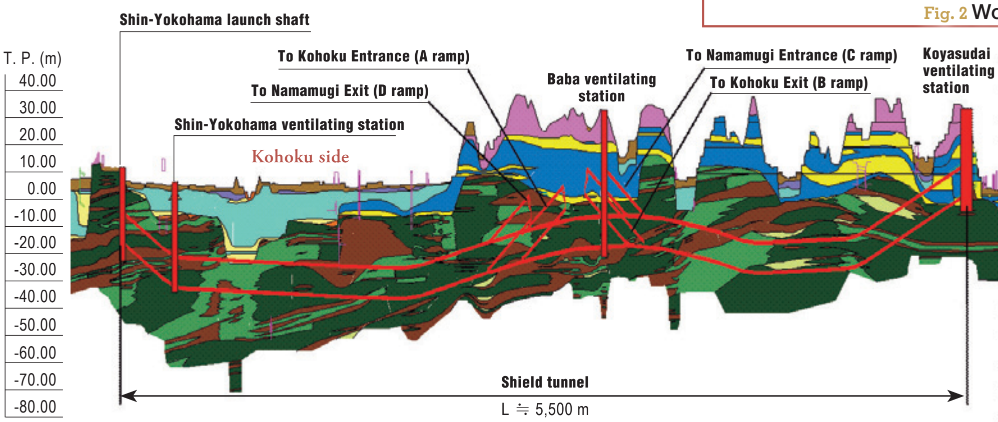


Fig. 2 Work sequence

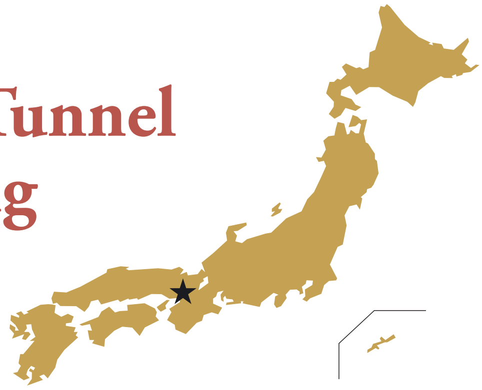


Stratigraphy

Period		Strata	Geology	Symbol
Quaternary	Holocene	Artificial ground	Embankment/ filling soil	B
		Alluvial	Highly organic soil	Ap
			Cohesive soil	Ac
			Sandy soil	As
			Sandy gravel	Ag
	Pleistocene	Loam	Loam	Lm
		Sagami group	Cohesive soil	Dc
			Sandy soil	Ds
Neogene	Pliocene	Kazusa group	Mudstone	Km
			Sand/ sandstone	Ks
			Alternate layers of mud and sand	Kalt
			Sandy mudstone	Kms

Fig. 1 Geological profile of the tunnel

Design and Construction of a Tunnel with Composite Side Wall Using Perfobond Strips



Takashi **NAKASHIMA** ▸ Assistant Manager,
Osaka Construction Department, Hanshin Expressway Company Limited

The Shorenji-gawa Tunnel on the Hanshin Expressway Yodogawa Sagan Route No. 2, is located in the north-west part of Osaka City. In this site, the earth retaining wall was integrated into the permanent tunnel structure, resulting in cost reduction. This is the first use of this technique for road tunnel projects in Japan.

Overview of the technology

In cut-and-cover tunneling projects, a cast-in-place pile wall is often used for retaining earth. The core of the earth retaining wall is wide-flange beams, which are not necessary after construction and left underground as they are (Fig. 1). The composite side wall structure effectively utilizes the wide-flange beams by integrating them into the tunnel side wall (Fig. 2). This structure makes it possible to reduce the concrete thickness of side wall, thereby diminishing concrete volume. In addition, since the overall construction width is smaller, excavation soil volume and cost for land acquisition can be also reduced.

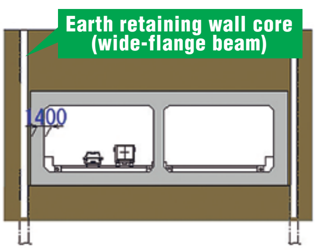


Fig. 1 Tunnel structure without integrating the earth retaining wall core

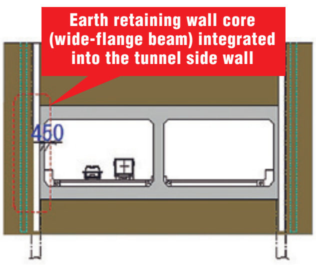


Fig. 2 Tunnel with composite side wall

Design

We developed the composite side wall structure and applied it to a part of the Shorenji-gawa tunnel project, resulting in reduction of side wall concrete thickness from 1.4 m to 0.45 m. For integrating of wide-flange beams into the tunnel structure, perfobond strips (PBL: Perfobond-Leiste) were used, which have been successfully utilized in bridge projects (Figs. 3 and 4). Because PBL does not interfere with reinforcing bars in the tunnel side wall, assembly work of reinforcing bars became easier. (Fig. 5).

In designing the composite wall, it is necessary to validate the behavior of PBL against shear forces acting in the connection plane. Three failure modes of PBL can be supposed: 1) shear failure of concrete, 2) split failure of concrete,

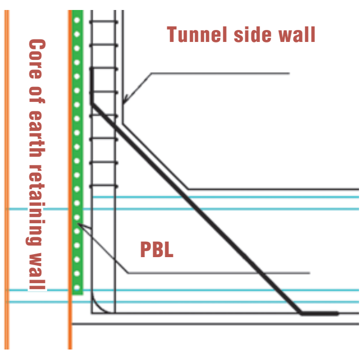


Fig. 3 Structure of the side wall section

and 3) shear failure of steel plates between holes. Of these three failures that presenting the minimum strength is taken as the design capacity of PBL. For workability improvement, aimed at a PBL weight that can be conveyed by a single worker for ease of work, a study on reducing weight of PBL was conducted, with steel plate thickness and hole interval taken as parameters.

As a result of the study, the following specification was determined: steel plate 9 mm thick and 120 mm high, hole diameter 80 mm, center-to-center distance of holes 150 mm, with D13 reinforcing bars going through the holes. With this specification, a failure mode was shear failure of steel plate between holes.

A prototype specimen simulating the side wall was used for a shear loading test, to measure relative displacement of concrete and wide-flange beams. The test result showed a load-displacement relationship almost linear up to the allowable shear capacity. The maximum shear capacity given by the test was 1.1 to 1.3 times greater than the calculated shear capacity, proving suitableness of the calculation formula.

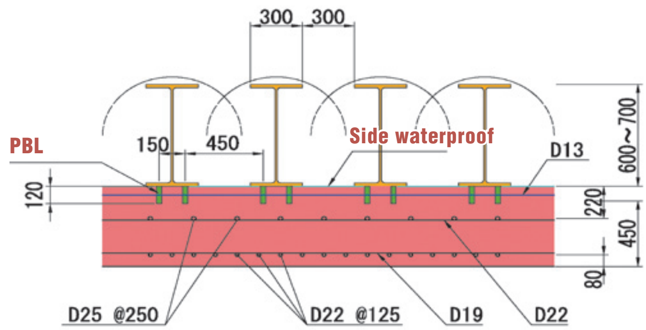


Fig. 4 Plan of the structure

Fig. 5 Assembled PBL and side wall reinforcement

Construction

Quality was the primary concern in construction of permanent tunnel structure. Each wide-flange beam was erected with an inclinometer mounted on it to ensure accurate installation. The PBL and wide-flange beam were joined by one-sided fillet welding. To minimize strain of the PBL due to welding heat, weld points were staggered. Concrete was placed for the side wall and top slab without construction joints. A chute for concreting was installed in the narrow section of the side wall to prevent segregation of concrete.

Controlling Displacement and Environmental Impact on a Twin Tunnel with Tubes Extremely Close to Each Other

- Construction of the Kyoto Second Outer Ring Road -

Akihisa **IWAMOTO** ▸ Kyoto National Highway Office, Kinki Regional Development Bureau, MLIT

The Kita-Kasuga Tunnel is located on the Kyoto Second Outer Ring Road of national route #478. This road is a motorway 15.7 km long, running in the north-south direction in the northwest Kyoto. It links with the Meishin Expressway, serving as a circular route for vehicles in the Kyoto urban zone, alleviating traffic congestion and improving regional activity, thereby improving the function of the wide area traffic network in the Kinki district. The tunnel in Photo 1 is in Oharano area of Nishi-yama mountain, one of the beautiful Three Kyoto Mountains. In the vicinity, there are the Oharano shrine originating from Nagaoka-kyo, the ancient capital of Japan and the Shojiji temple famous for cherry blossom.

Overview of the tunnel structure

As shown in the geological longitudinal profile in Fig. 1, the tunneling site is unconsolidated ground constituted of alluvial fan deposit, terrace deposit and Osaka group. The overburden is very small, approximately 3 to 15 m. The alluvial fan deposit above the tunnel is composed of clayey gravel and clay mixed with pebbles, exhibiting deposits of debris flow. The terrace deposit below the alluvial fan deposit is mainly composed of clayey gravel. The Osaka group is marine sediment. It was deposited in the marine area generated by sea water flowing in the Kyoto basin through Osaka Bay several times in the past. This group is mainly composed of uniform clay and silt, with intercalated sand and gravel strata. For the Kita-Kasuga tunnel, a waterproof structure was adopted from the viewpoint of environmental conservation. Therefore, the design load assuming loads after completion of the tunnel considered not only earth pressures, but also water pressures. Thus, it was assumed that very large loads would be applied on the tunnel structure.

The sectional shape of the standard section of the tunnel is circular, about 10 m in inner diameter and approx. 100 m^2 of sectional area, and that of the widened section is oval, about 14 to 15 m in inner diameter and approx. 200 m^2 of sectional area. The auxiliary methods used in the standard section were steel tube long forepiling with grouting, face bolt and shotcrete on tunnel face, and ground improvement in the widened section.

Measures for controlling deformation

In order to predict the behavior of the large section circular tunnel during invert excavation, FEM analysis was performed. To simulate the measurement data previously obtained, post analysis was conducted. The analytical results showed that sudden increase of displacement was caused by plasticization of almost all the pillar region as the second tube on the northbound line, impairing stability of the ground around the tunnel.

To evaluate the results of FEM analysis, additional geological surveys were conducted, the strength parameter was validated, and the prediction was analyzed for the behavior during invert excavation with no deformation controlling measures taken. The analytical results demonstrated that the settlement of the tunnel and conversion of the bench would increase further. On the basis of the analytical results, binding the tunnel with prestressing bars and improvement of the lower section of the upper half by mortar piling were examined as shown in Figs. 2 and 3.

Both displacement control methods were analytically proved to be effective. Considering the characteristics of each method, the preferable one was selected, which was suitable for controlling displacement of each location.

As a result of the measured displacements with these control methods, the settlement was slightly larger than the analytical value, but within the control criterion, and the convergence was about 50% of the analytical value. In conclusion, both control methods were sufficiently effective.

Photo 1 Kita-Kasuga Tunnel

Alluvial fan deposit (clay soil)	Fm
Alluvial fan deposit (gravel soil)	Fg
Terrace deposit (clay soil)	THm
Terrace deposit (gravel soil)	THg
Osaka group (clay soil)	Om
Osaka group (sandy soil)	Os
Osaka group (gravel soil)	Og

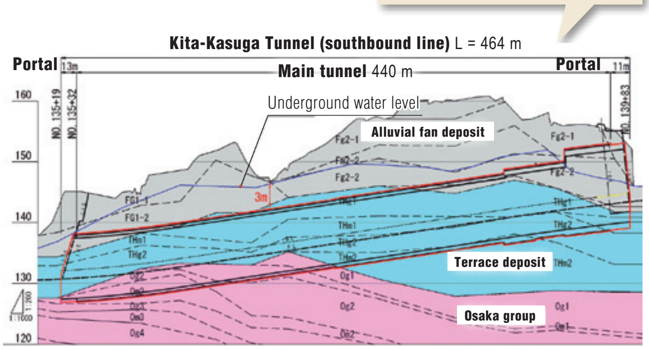


Fig. 1 Longitudinal profile

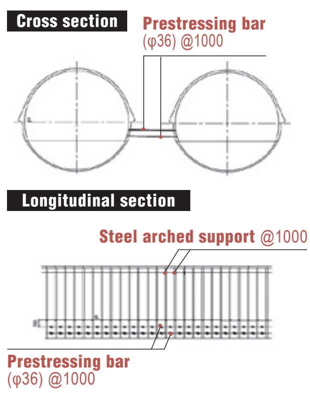


Fig. 2 Displacement control with prestressing bars

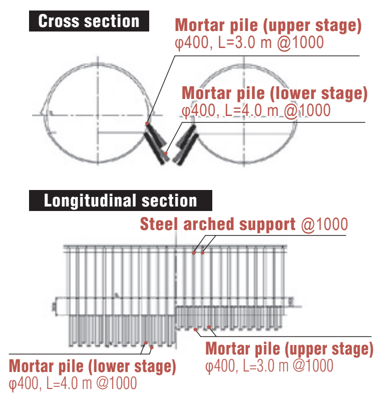


Fig. 3 Displacement control with mortar piling

World's Longest 150 m Pipe Roof for Full Face Excavation of a Large-section Box-shaped Tunnel

- Chiyohara Tunnel on National Highway No.9 -

Hiroyuki **Tanaka** ▸ Senior Manager, Kajima Corporation, Kansai Branch

National highway No.9 had suffered chronic traffic congestion due to recent increase in traffic volume. The project discussed here was to construct a grade separate crossing with an underpass at Chiyoharaguchi six-forked road that was one of the main causes of traffic jams on national highway No. 9 in Kyoto City. To minimize the impact of the work on the traffic, non-open cut method was selected for constructing a large-section box-shaped tunnel with the world's longest 150 m pipe roof. This work includes challenging tasks such as location just below the trunk national highway in the city, long distance, small overburden, water-bearing gravel ground with boulders, proximity to buried infrastructure elements and remaining underground obstacles. Thanks to this non-open cut method, providing no open sections such as intermediate vertical shafts in the junction, tunneling work proceeded without producing severe traffic congestion, and reduced the noise and sources of vibration.

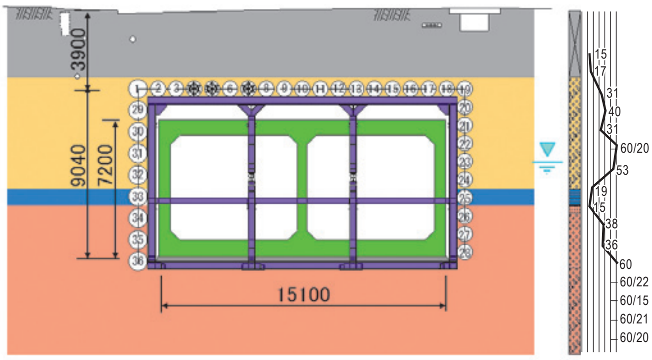


Fig. 1 Non-open cut section

Photo 1 Pipe roof drilling machine

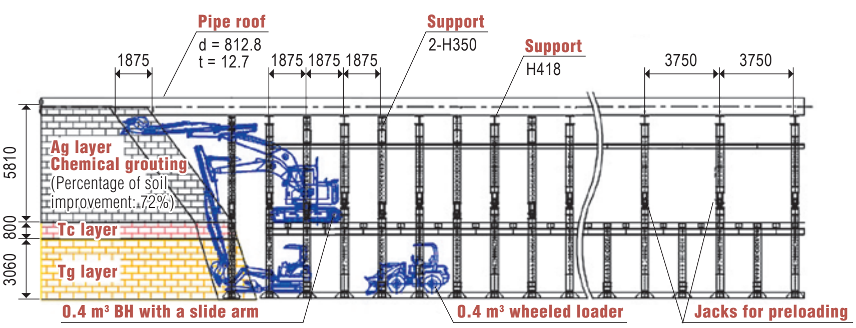


Fig. 2 Schematic of excavation procedures

To cope with these challenges, the following technological developments were made.

Full face excavation of large-section box-shaped tunnel (excavation height 10 m x width 17 m) with pipe roof.

a) Evaluation technique of face stability considering deformation of the pipe roof

b) Full face excavation using auxiliary methods (groundwater lowering and chemical injection) to prevent the collapse of water-bearing sandy gravel ground with boulders.

Construction techniques of pipe roof covering a long distance

a) Optimized technique of constructing the pipe roof (0.8 m and 1.0 m in diameter) suitable for the severe conditions: long distance, small overburden (approx. 3.5 m), and water-bearing gravel ground with boulders (max. boulder diameter 30 cm).

b) Pipe roof construction by means of a vertically-doubled cutter unit combining upper and lower cutters (1.0 m in diameter), for enabling excavation while manually removing underground obstacles (electric utility ducts, remaining steel sheet piles) at the pipe roof cutting face.

c) Excavation lubricant, to minimize ground settlement caused by interstice (overbreak about 3 cm) between steel pipes and the ground.

d) Filling material and construction technique for surely filling the long-distance steel pipes.

Development of groundwater level automatic control technique with inverter-controlled pumps

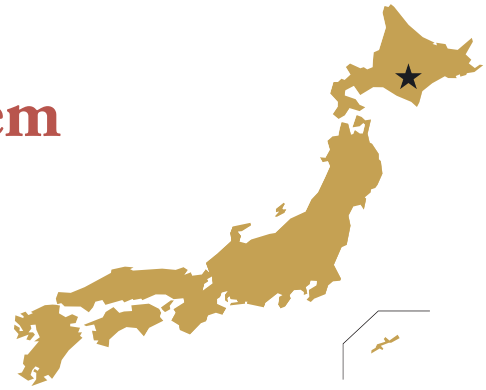
This technique reduced the pumping volume by about 35% using the conventional technique, thereby avoiding impact on the surrounding ground water, such as wells' drying up.

These new techniques were applied to the project of the Chiyohara Tunnel on national highway No. 9 and enabled construction of the underpass with the world's longest 150 m pipe roof, with improved work efficiency. Moreover, the techniques didn't impact the traffic.

Photo 2 Main tunnel construction (inside of the tunnel)

New Water Seal Grouting System

- Construction of the Kitanomine Tunnel in Furano City on the Asahikawa-Tokachi Road -



Satoru **KOBAYASHI** ▶ Asahikawa Development and Construction Department, Hokkaido Regional Development Bureau

The Kitanomine Tunnel is a road tunnel, which is 2,928 m long and was constructed in Furano City that is famous for beautiful flowers, on the Asahikawa-Tokachi road (120 km) a north-south road in Hokkaido. The rich groundwater environment around the tunnel had to be preserved and tunnel excavation was required to be environmental friendly. In addition, ground stability had to be ensured, since the geological survey showed the existence of an active fault and a confined aquifer.

To achieve the objectives described above, a new water seal grouting system was used for the waterproof zone in Figs. 1 and 2. This article introduces the design and construction of the grouting.

New grouting material
- Finer ultrafine cement -

Finer ultrafine cement, whose average grain size was 1.5 μm, shown in Fig. 3, was selected for grouting, which was finer than the usual extremely fine cement. This finer ultrafine cement made it possible to improve both water sealing and ground stability.

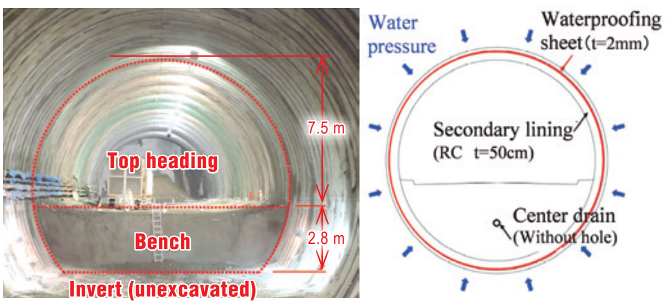


Fig. 1 Waterproof tunnel section

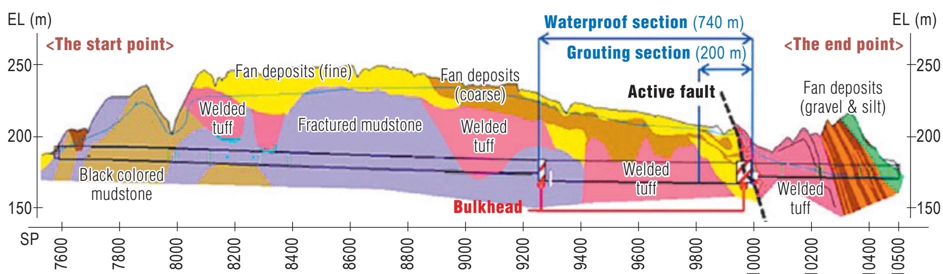


Fig. 2 Geological profile

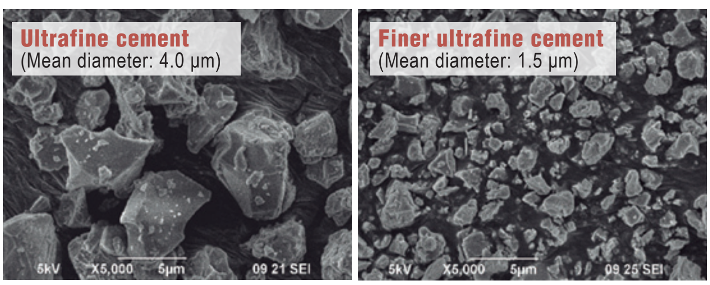


Fig. 3 Electron microscope photograph

Efficient grouting control method
- 3D grouting control system -

A three-dimensional grouting control system was selected for this project. This system can depict the daily grouting data in three dimensions including grouting material, date, injection volume and pressure, and was able to control complex grouting properties efficiently.

Confirmation of grouting efficiency
- 3D resistance tomography and water permeability test -

To confirm grouting efficiency, three-dimensional specific resistance tomography in Fig. 4 was selected and in-situ permeability test was conducted. In the zone shown in Fig. 4, only the upper half of the tunnel was sealed with grout. The specific resistance change rate significantly increased after grouting, demonstrating that the grout was applied in a suitable zone.

The results of the in-situ permeability test showed that variance in results were large, with a water permeability coefficient of 10^{-4} cm/sec order before improvement. The results after improvement concentrate in the order of 10^{-5} cm/sec. This proved that grouting improved the water sealing effect.

Excavation in the watertight zone

This grouting method ensured effective water sealing and ground stability in the weak geology including faults. Excavation could proceed safely without unusual water inflow or displacement.

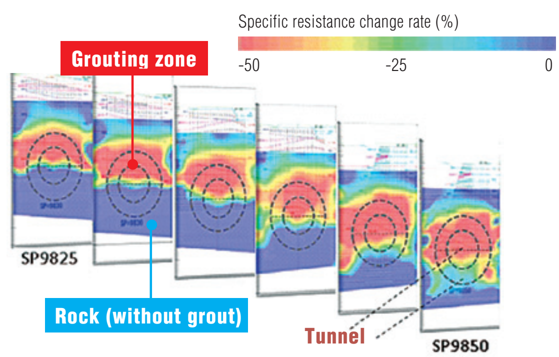


Fig. 4 3D resistivity tomography

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Construction Project between Yubari and Shimukappu on the Doto Expressway

- Construction of Long Tunnels through a Weak Serpentine Belt -

Kazuyuki **MIZUGUCHI** ▸ Chitose Construction Office, East Nippon Expressway Co., Ltd.

The Doto Expressway (between the Yubari and Shimukappu interchanges) was opened to service in October 2011. The expressway runs east and west passing through the Yubari and Hidaka mountains near central Hokkaido. Fifty percent of the total length of the section in service runs through tunnels. The route goes through a mountainous area where landslides occur frequently, and the geology is composed of widely distributed mudstone of Paleogene, which is brittle and liable to weathering, and swelling serpentine. It was anticipated from the planning phase that the work would be challenging.

East Nippon Expressway Company deemed that delay in tunneling would significantly affect the overall progress of road construction. Therefore, an engineering study committee was established at an early stage to study the items discussed below. Based on the study, effective measures were taken during construction, and as a result, the section was opened to service without delay in schedule.

Items studied

(1) Tunnel portal construction in the topography prone to landslide

Through in-depth preliminary surveys, the portal location was planned so that impacts of landslides could be avoided as much as possible. Where impacts of landslides were unavoidable, the ground was stabilized by constructing drainage wells, carrying out drainage boring, and changing the structure by diversion of the river. (Photo 1)

Photo 1 Landslide prevention

(2) Construction in weak serpentine

The Hobetsu tunnel has an overburden of about 400 m and goes through a serpentine belt, which is very brittle with a competence factor of about 0.2. To cope with this problem, an evacuation drift was excavated before the main tunnelling, and measurements were taken and analyzed. The analytical results were referred to in the study and designing of support structure for the main tunnel.

The support structure was designed with a quasi-circular sectional shape to resist large squeezing ground pressure and a double support using high-strength members. In order to minimize loosening of the ground due to excavation, the section was closed early, that is, the invert was constructed about 10 m behind the face (Photo 2). Furthermore, to stabilize the face, supplementary methods were used, such as long forepiling. As a result, even in the brittle geological structures, the ground was excavated stably.

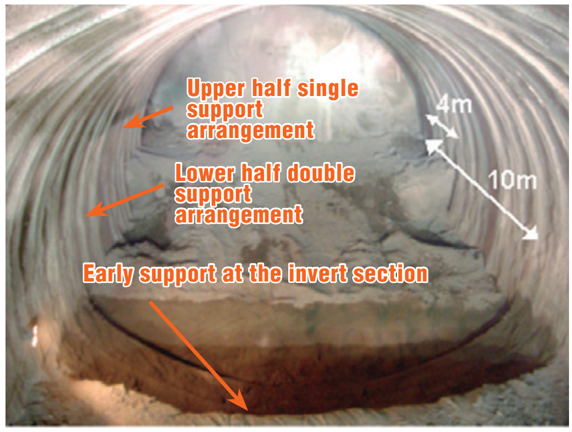


Photo 2 Early section closure

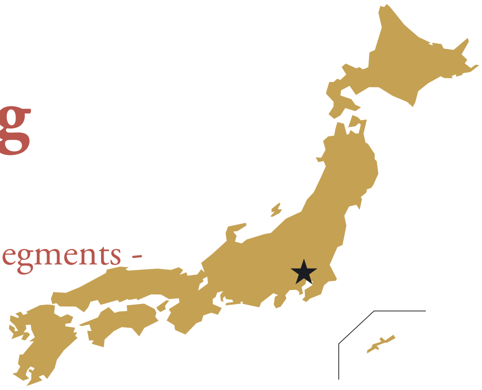
(3) Measures against methane gas

In the vicinity of the site, a methane gas explosion accident once occurred during tunnel construction. From the lesson learned through this accident, existence of methane gas was checked by boring prior to excavation of each tunnel (Photo 3). In the Hobetsu and Shimukappu tunneling sites where methane gas was found, measurements of methane gas concentration were taken more frequently, and bringing fire in the tunnel was prohibited. In addition, an instruction manual was prepared that showed measures to be taken when methane gas was found to enable prompt action to prevent accidents.

Photo 3 Methane gas blasting out

Tunnel Construction Preserving the Hydraulic Environment

- Waterproof Grouting in the Ground and Early Lining with Segments -



Hisashi **TAMURA** ▶ General Manager (Engineer),
Sobu National Highway Office, Kanto Regional Development Bureau, MLIT

Yukio **YOSHITOMI** ▶ Construction Engineering (Tunneling) Department,
Civil Engineering Division, Taisei Corporation

The Takaosan Tunnel in Photo 1 is composed of two tubes with two lanes each 1.3 km long, planned at 40 to 60 km from the center of Tokyo on the Metropolitan central link motorway (Ken-O Expressway). Since the Takaosan Tunnel is located in a national park and passes through a nature-rich district, it is necessary to preserve the hydraulic environment during construction. Therefore, the area 500 m long under a river was designed with a waterproof structure. In order to minimize water inflow into the tunnel during construction, an advancing drift was bored with a rock shield machine, with injection for a 5-meter range from the tunnel. Then, the drift was enlarged by mechanical excavation and lined with reinforced concrete segments to achieve a waterproof structure at an early stage as shown in Figs. 1 and 2.

Water sealing injection in the ground

After the advancing drift was completed with a rock shield machine, 10 boring machines capable of swiveling 360 degrees were installed from the drift inside and injections were performed in both tubes simultaneously.

To increase the work efficiency of grouting, a central plant installed in the entrance of the advancing drift supplied high density grout constantly in the pipeline, and the diluted grout was distributed with diluting equipment in the sub-plant to each injection point. A total of 140 grouting machines were installed in both tubes, and numerous points of boring and grouting data, gathered through optical cables, were controlled at the plant at the drift entrance.

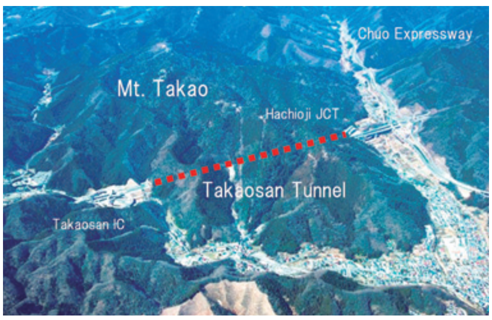


Photo 1 Overview of the Takaosan Tunnel

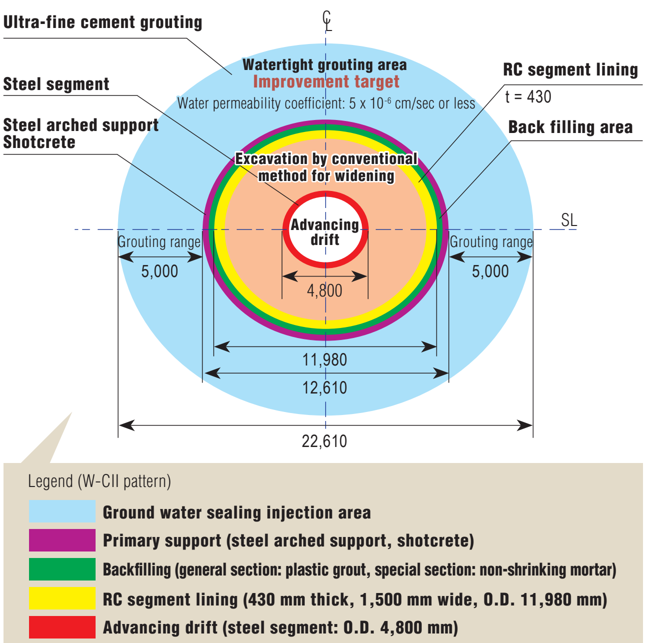


Fig. 1 Cross section of the waterproof structure

Lining with reinforced concrete segments

To assemble reinforced concrete segments simultaneously with excavation processes, a specific segment erection system was manufactured. The system was composed of three sections: invert placement section, segment erector and segment carrier. It can carry and assemble segments, and grout maintaining the movement route to face, and move corresponding to the advance of excavation.

Confirmation of effect of water sealing in the ground

The effect of the grouting was verified with a water permeability test conducted from the advancing drift. In all the sections, the improvement target, under 5×10^{-6} cm/sec, was achieved. As shown by the results of the hydrological monitoring in the river above the tunnel, the flow rate did not change before and after advancing drift excavation, during tunneling and after completion of segment lining. This demonstrates the effectiveness of the waterproof structure.

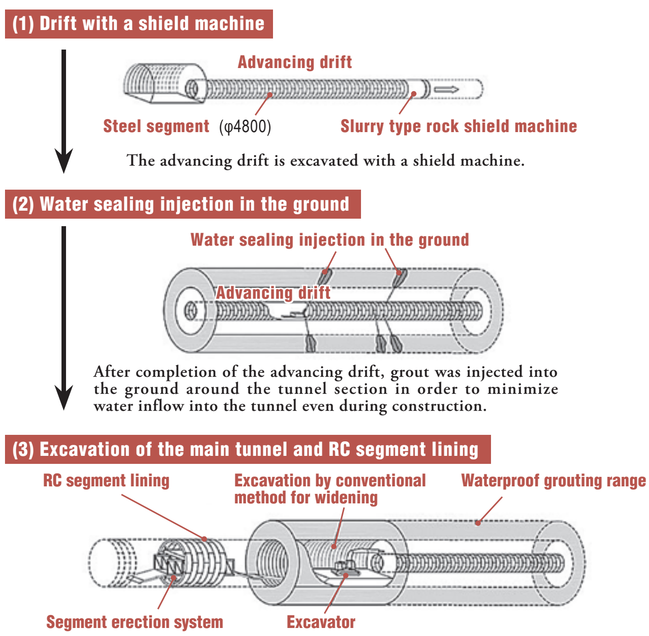


Fig. 2 Construction method of the watertight structure zone

Tunnel Construction in Unconsolidated Sandy Ground Using Various Auxiliary Methods

- 2nd Utatsu Tunnel on the Kanazawa Eastern Ring Road -

Mitsuo **ARINO** ▶ Chief
Kanazawa Office of River and National Highway
Hokuriku Regional Development Bureau

The 2nd Utatsu Tunnel on the Kanazawa Eastern Ring Road is a road tunnel as part of a project to widen national road No. 159 into 4-lane route. This Tunnel is 1,200 m long in proximity to the 1st Utatsu Tunnel whose traffic volume is currently 37,000 vehicles/day, and the center-to-center distance of these tunnels is 2 to 2.5D (D = tunnel diameter).

Geological overview

The geology is composed of, from the lower level, Onma formation of the early Pleistocene, Utatsuyama formation of middle Pleistocene and upper terrace deposit (sand, mud, gravel) of late Pleistocene.

The predominant Utatsuyama formation is mainly composed of unconsolidated to semi-consolidated fine to medium grain sandstone, with three to five intercalated alternate layers of mudstone and conglomerate. The geology at the face is, from the portal to TD100 m, relatively consolidated Onma formation sandstone, and in the succeeding section to TD414 m, Utatsuyama mudstone formation whose unconfined compressive strength is about 2,000 kN/m^2. Beyond these sections, Utatsuyama unconsolidated sandstone formation is distributed throughout the tunneling site, whose coefficient of uniformity Uc = 1.5 to 2.9 and fine fraction Fc = 0.2 to 6.9% is very prone to quicksand (Fig. 1).

Auxiliary methods used for the Utatsuyama sandstone formation

In the unconsolidated Utatsuyama sandstone formation, “long grouting forepiling (All Ground Fastening: AGF),” and “long face bolt” were used. Referring to the results of the test of grouts at the portal, “special water glass solution” was selected.

During excavation, crown and side wall collapses due to quicksand were observed. However, by improving the auxiliary methods through study of the site conditions, construction was economical and safe .

The auxiliary methods utilized in the ground most prone to quicksand (section length: about 500 m) were the following.

Crown stabilization
-Double-row AGF (staggered) (Fig. 2)
-Grouting with one packer and three valves (Fig. 3)
Sidewall stabilization
-Grouting forepoling (closed injection)
-Foamed urethane solution (highly permeable type)

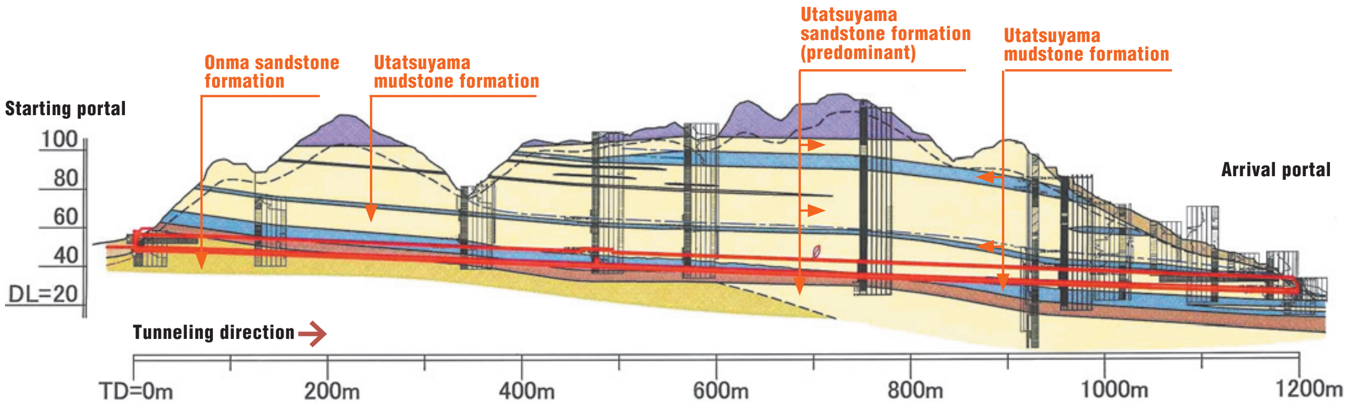


Fig. 1 Geological profile of the 2nd Utatsuyama Tunnel

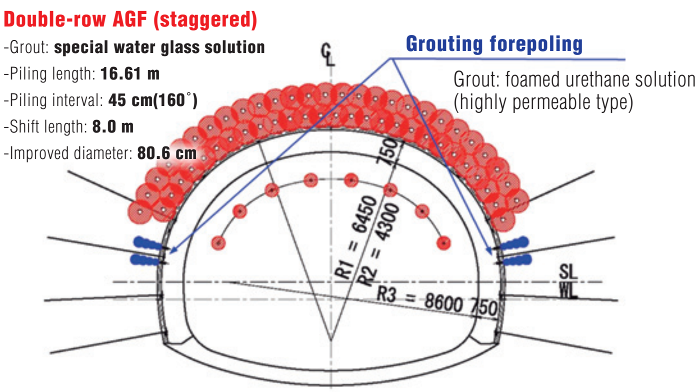


Fig. 2 Support pattern using various auxiliary methods

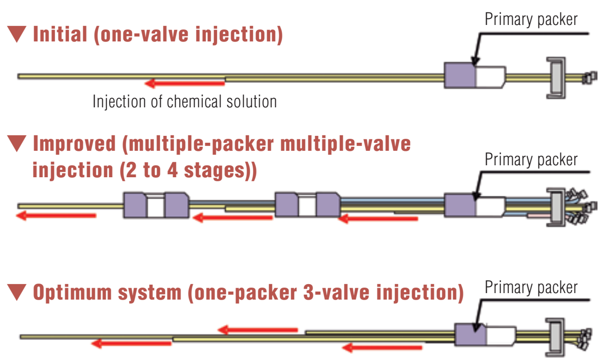


Fig. 3 Improved progress of injection system

Reconstruction of an Invert without Interrupting Traffic, the First Attempt for an Expressway in Japan

- Nikkureyama Tunnel on the Joshinetsu Expressway -

Kiyoyuki **AMANO** ▸ Saku Management Office, East Nippon Expressway Co., Ltd.

Status of deterioration

The Joshinetsu Expressway is a national highway, 203 km long, linking the Tokyo metropolitan area with Hokuriku districts. The Nikkureyama Tunnel is located at the boundary between Nagano and Gunma prefectures, a one-way traffic tunnel 2,000 m long. Eight years after opening to service, in August 2010, the invert was damaged and the road surface heaved about 5 cm, which was confirmed to be progressive.

Design and execution of reconstruction

The reconstructed range was 40 m long. In order to furnish a larger resistance, the invert was designed in a quasi-circular shape, with a radius double the upper half radius. Repair was planned for each lane separately and carried out by closing one lane at a time. For this purpose, the new invert of the lane placed first was connected with the old invert (the remaining lane) using steel arch supports (section closure), to curb deformation (Fig. 1). The concrete for the invert was mixed with steel fiber (0.5 vol.%) to get the strength set at 24 N/mm^2. The width of invert placement per work cycle was 6 m determined on the basis of numerical analysis conducted in advance. The left and right lanes were divided into seven blocks each. The invert was reconstructed on the right lane first, then the left lane (Photo 1).
The damage of the old invert was due to cracks penetrating through the concrete (Photo 2). During reconstruction, an undesirable event occurred. When a cutter was placed into the pavement slab, the road surface heaved. Even after the invert was placed on the right lane and provisionally connected with the old invert on the left lane, displacement remained. It was after completion of the new invert placement on the left lane that displacement finished (Fig. 2).

Photo 2 Damage of the old invert

Presumed cause of the damage

Although the geology of the damaged section was assumed to be solid andesite, it was in fact alternating strata of weak mudstone and tuff. It was presumed that water flowed into this ground from the center drain, and plastic ground pressure increased for a long time, which damaged the invert.

Result of the reconstruction

Although the reconstruction took a long time, 61 days, it was completed successfully by regulating traffic continuously day and night.

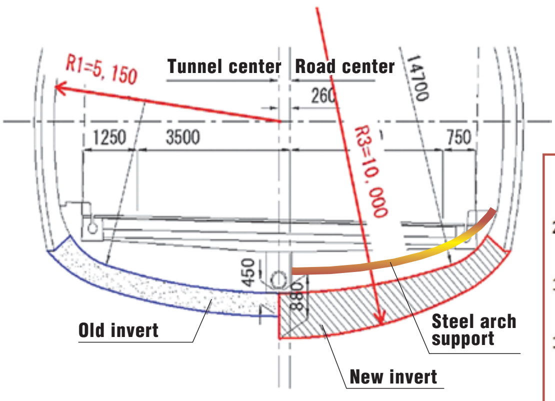


Fig. 1 Invert geometry considering lane closure

Photo 1 Repair of the left lane

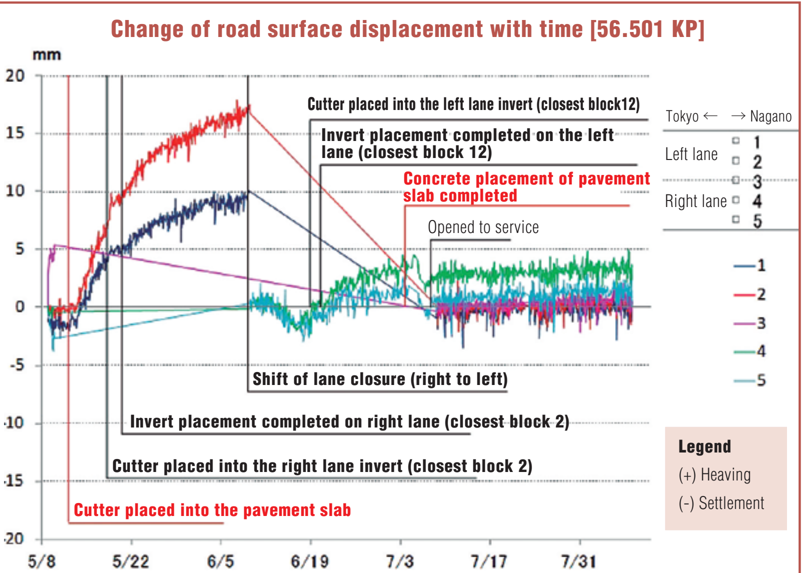


Fig. 2 Change of heaving of the road surface with time (maximum displacement point)

Dual Shield for Sewer Tunnel under a Sharply Curved Narrow Road

Jun WADA ▸ Director
Reconstruction Promotion Section, North Sewerage Office,
Bureau of Sewerage,
Tokyo Metropolitan Government

The bureau of sewerage of the Tokyo metropolitan government is promoting a "reconstruction project" for the purpose of maintaining and replacing aged sewers and improving rainwater drainage capability. This article introduces a case of placing sewer pipes under a sharply curved narrow road in an urban area, using the dual shield method.

Overview of the project

Near Komagome in Toshima ward, Tokyo, flood damage occurs frequently due to localized heavy rain. To cope with this problem, a sewer of 1,100 mm in inner diameter was planned in order to improve rainwater drainage.

Dual shield method

Most roads in the district discussed here are too narrow to construct a shaft midway. Furthermore, since the locations of the starting shaft and junction with the trunk pipes were already determined, the route of the planned sewer was unchangeable. (Fig. 1). This route was to be constructed by a non-open cut method and included eleven curved sections (about 250 m) with two small-radius curves (R = 13 m). However, there is a long straight section (362m) at the starting point of the tunnel. Therefore, a selected construction method was the dual shield method that combines pipe jacking for the straight section and shield tunneling for the curved section. By using pipe jacking for the straight section, the construction cost is much smaller than the case of using the shield machine over the entire route.

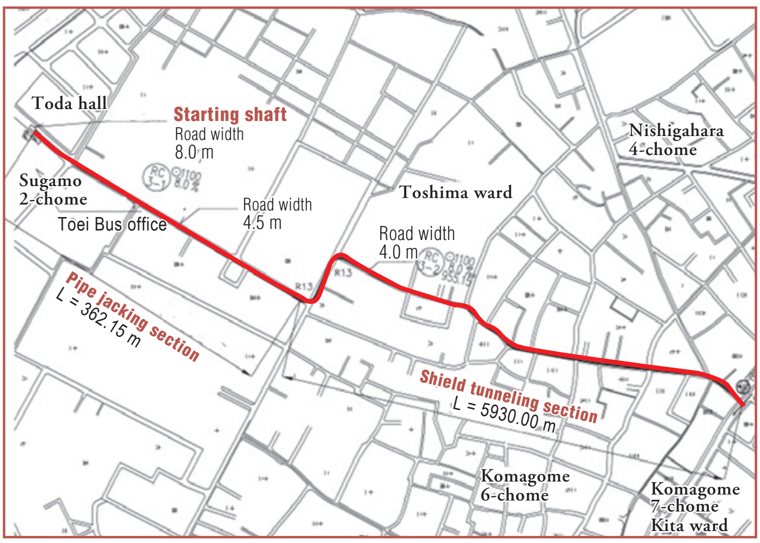


Fig. 1 Plan alignment

Construction

Since the design is suitable for the sharp curve (R = 13 m) of this project, an "articulated 3-stage 4-shell excavator" was used (Photo 1). This machine is composed of four shells, i.e., front, middle, rear and jack shells, with an articulating angle of 14 degrees. Since the machine length, 10 m, is relatively large compared with the excavator outer diameter, an anti-rolling stabilizer was installed on each side of the machine. Although survey instruments must be relocated frequently at the curves, the use of an automatic tracking total station proved effective to reduce the time required for survey (Photo 2).

All these measures enabled safe excavation without serious accidents in 236 days from start to arrival. The daily advance was 5.6 m in the pipe jacking section, and 4.2 m (2.8 m in the sharp curve) in the shield tunneling section.

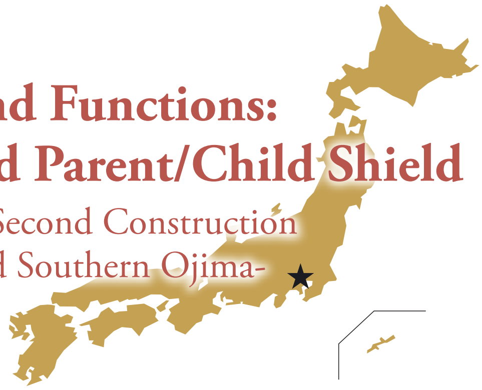
Currently, secondary lining is being placed. We will proceed with work on a safety-first basis, aiming at completion in the middle of 2015.

Photo 1 Main assembly of the excavator

Photo 2 Installation of automatic survey equipment

Shield Tunneling Provided with Compound Functions: DO-Jet, Sharp Curve, Separation of Nested Parent/Child Shield

- Bureau of Sewerage, Tokyo Metropolitan Government: The Second Construction of Main Sewerage Tunnels for Rainwater in Eastern Ojima and Southern Ojima-



Yoji **HISAMOTO** ▸ Director
First Construction Section, First Core Facilities Reconstruction Office,
Bureau of Sewerage, Tokyo Metropolitan Government

The Eastern Ojima and Southern Ojima main sewers are trunk pipe lines that manage rainwater in Koto ward and part of Edogawa ward, Tokyo. This project includes the Eastern Ojima main sewer about 0.7 km long (6,000 mm in inner diameter) and the Southern Ojima main sewer about 0.8 km long (4,500 mm in inner diameter).

Since it was difficult to provide land for a shaft at the junction of the Eastern Ojima and Southern Ojima main sewers, where the sectional area varies, this project used the double shield (nested parent/child shield) tunneling method.

The tunnel runs near foundation piles of abutment of the Kyu-Naka River and the existing main sewer. It is therefore necessary to stabilize ground for avoiding impact on the structures in the proximity. On the planned tunneling route, temporary piles for a common duct, etc. are left, impeding the excavation. However, it is difficult to stabilize ground and remove obstacles from the surface, because the common duct, etc. exists just above the planned sewer route. Accordingly, a special high-pressure agitating pile method (DO-Jet "Double Object- Jet" method) was selected, which makes it possible to stabilize ground and cut/remove obstacles from the shield.

Overview of the project

(1) Ground condition

The geology of the site is cohesive soil characterized by N value of 1 to 5, maximum cohesive force C = 40 to 100 kN/m^2, and pore water pressure of 220 kN/m^2 at GL – 30 m.

(2) Alignment

The plan alignment is as follows. S-shaped curve with right-hand curve and left-hand curve of 40 m in radius, just after the parent shield start, and left-hand curve of 35 m in the minimum curvature radius. After separation of parent and child shields, the child shield follows a right-hand curve whose minimum curvature radius is 25 m. The vertical alignment is upward gradient of 0.8 to 5.0‰.

(3) Shield machine

To cope with the special excavation conditions, the shield machine is equipped with compound functions: 1) excavation at a large depth (overburden GL -25 to 40 m) in a layer charged with methane gas (explosion proof), 2) sharp curve (minimum curvature radius = 25 m), 3) Starting from NOMST (Novel Material Shield-Cuttable Tunnel Wall System) (wall thickness 2.8 m), 4) provided with DO-Jet equipment, 5) Double shield (outer diameter 7100 mm (parent) to 5340 mm (child)).

(4) Segments

Reinforced concrete segments are used, that need no secondary lining (1200 mm wide) for the general section, steel segments (300 mm wide) for the sharp curve section, concrete-filled steel segments (1200 mm wide) for the junction with another main sewer, and flexible segments for the connection to the shaft.

Construction progress

Excavation started in May 2012. As of November 2013, the shield is advancing about 1.0 km from the start point. Challenging tasks such as NOMST start, sharp curve excavation (R = 40 m, 35 m), DO-Jet (ground improvement) and separation of double shield (starting the child shield) have been performed without any trouble.

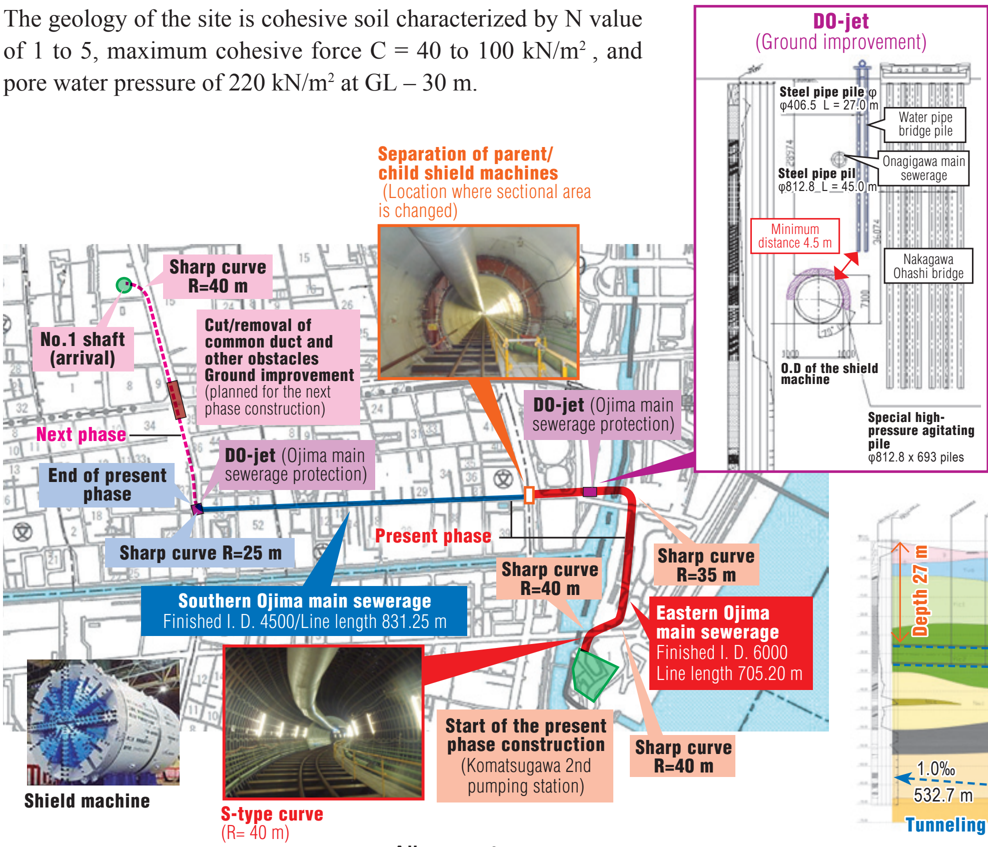


Fig. 1 Alignment

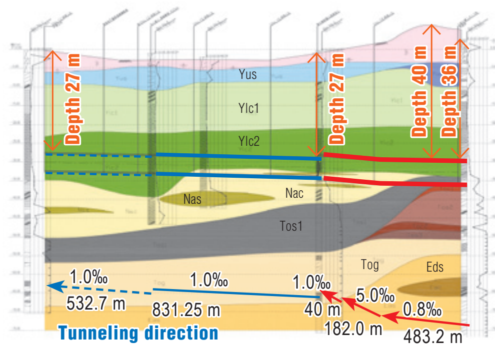


Fig. 2 Geological longitudinal profile

Excavation Methods for a Cavern at the Tokuyama Hydro Power Plant

Kunio **NISHIZAWA** ▸ Tokuyama Hydro Power Plant Construction Office, Chubu Electric Power Co., Inc.
Ryusuke **ANDOU** ▸ Tokuyama Hydro Power Plant Construction Office, Chubu Electric Power Co., Inc.
Hidemasa **SAKA** ▸ Chief, Tokuyama Construction Department, Nagoya Branch, Kumagai Gumi Co., Ltd.

In Main Generator Hall 1 of the Tokuyama Hydro Power Plant, a cavern houses the primary machinery (hydraulic turbines and generators) of Unit 1, which generates 131,000 kW (the maximum output of the power plant is 153,400 kW) of the power plant. The excavation of Machine Hall 1 began in June 2011 and was completed in April 2013. For construction of the cavern, the first priority was given to ensuring its stability, studying and adopting division of heading and a suitable construction order. In addition, excavation was implemented under severely restricted conditions, where a shaft was the only way to access the work site.

Noteworthy construction conditions

Due to the overall layout of the Tokuyama Hydro Power Plant, access to the cavern from aboveground had to be achieved not through a tunnel, but through vertical shafts. That is why, materials, machinery, workers, excavation muck, etc. were transported by crane, elevator and skip (mucking facilities for shaft), etc. through the shaft with a maximum depth of approximately 70 m (Fig. 1).

In mucking process, such lack of horizontal access to caverns has the greatest impact on a work process, so it was necessary to come up with an efficient way to progress the work . From this consideration, efforts were made to shorten the excavation cycle time by the following approach: from the process of enlarging the arch, the muck was cut, and then dumped through the shaft to the mucking drift located below for the muck to be hauled away. For this purpose, two shafts and two drifts were necessary. Based on this method, it was possible to excavate approximately 30,000 m^3 of cutting-down of bed in five months, in line with the work schedule.

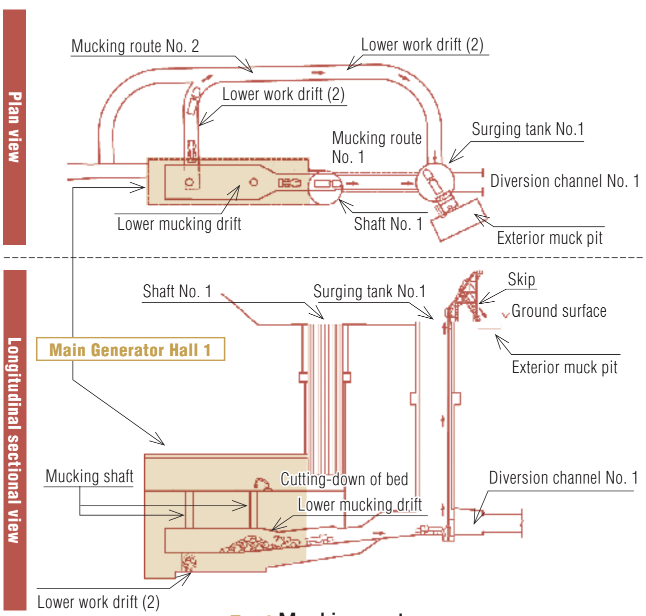


Fig. 1 Mucking route

Points of caution in construction work

The construction site is in the proximity of the Tokuyama Dam and has a shallow rock overburden. These were the main points of caution in the process of excavation of the cavern. Top priority was ensuring its stability during the excavation of the arch section. In view of these circumstances, the top and side drift advancing method was adopted. In the side drift, side wall concrete and PS anchors were constructed. As the next process, the arch section was enlarged.

This approach was adopted in order to curb the loosening of the bedrock caused by blast and excavation work as much as possible, with consideration of the fact that the cavern was designed as a mushroom-shape and the vertical load applied on the arch concrete is transferred to the bedrock that comes in contact with both bottoms of the arch concrete (Fig. 2).

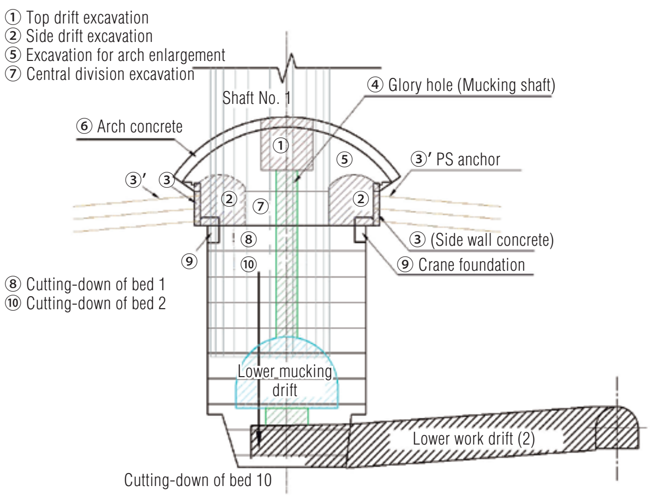


Fig. 2 Division of heading (Main Generator Hall 1)

Management by Observational Methods

In the power plant excavation process, observation of the face and sorting of observation results, as well as supervision of measurement data and comparison of such data with reference values were carried out as daily management operations. The information collected was tallied on a weekly basis, and the geological data was rendered in a three-dimensional format. Also, key block analysis was carried out, and analytical values and the actual bedrock behavior were compared. Based on these procedures, the adequacy of the current support and the necessity or non-necessity of reinforcement are examined by the observational methods.

Inside the cavern, there are three faults and one seam, so continuity from the arch section all the way to the invert was constantly checked and confirmed during excavation work. Thanks to the sound management by observational methods, excavation was completed successfully, without any special reinforcement in addition to the current support.

Connecting a Sluice Gate Caisson and an Intake Channel Shield below the Seabed

Takashi **SAITO** ▶ East Japan Railway Company

This paper describes a project for construction of an intake facility at the East Japan Railway Company (JR East) Kawasaki Thermal Power Station. The intake facility consists of the following three structures: an intake tank, which collects cooling water, a sluice gate through which cooling water flows, and an intake channel, which connects the intake tank and the sluice gate (Fig. 1). The intake tank has a frame body (W26.5 m×L60.0 m×D36.1 m) built using the cut and cover method. The sluice gate has a cylindrical shape (φ13.0 m, H22.8 m), and is immersed at a depth of approximately 23 m under the seabed (Fig. 2) using the pneumatic caisson method. The intake channel is composed of two tunnels (outside diameter φ4.6 m, inside diameter φ3.6 m) built using the slurry shield method, with the intake tank serving as the starting shaft and the sluice gate as the arrival shaft. The overburden of the tunnels is approximately 30 m, their length is approximately 570 m, and the isolation distance is 4.6 m. For the primary lining, reinforced concrete segments (H225 mm, W1,200 mm) were placed in the straight sections and steel segments (H225 mm, W450 mm or 900 mm) were placed in the curved sections. Concrete (200 mm thick) was placed as a secondary lining.

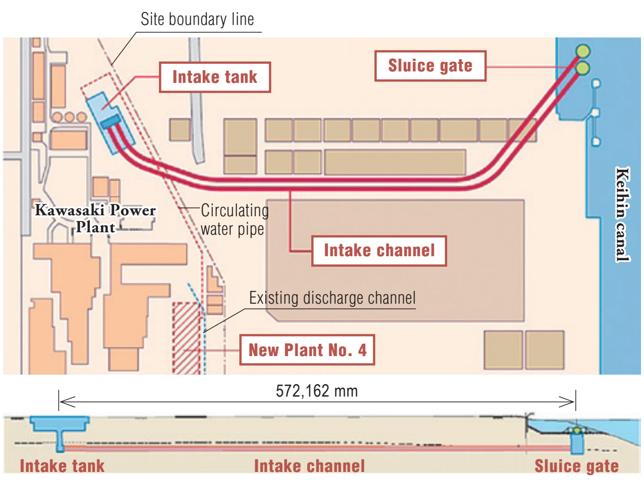


Fig. 1 A plan view and a cross-section of the overall construction project

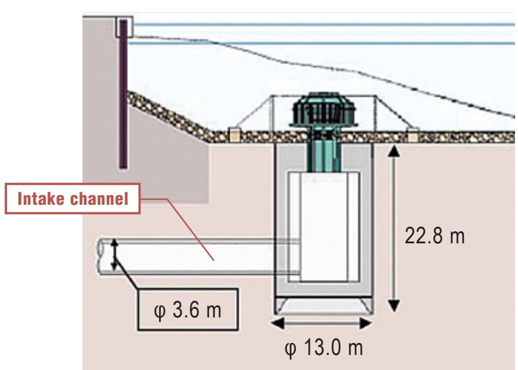


Fig. 2 Drawing of the sluice gate

The sluice gate, which constitutes the shield arrival section, was constructed as a caisson that served as an arrival shaft. The cutter unit of the caisson was installed at a depth of approximately 7 m below the water surface using floating cranes. After that, excavation in a sunken caisson was carried out (Photo 1). A shield arrival chamber capable of withstanding a high water pressure of approximately 0.34 Mpa was installed inside the caisson frame body. The ground at the location where the caisson was installed is composed of poor clayey soil with an N-value of 4 or lower. The ground at the final installation location, which serves as the shield arrival section, is composed of sandy soil with an N-value of 50 or higher.

Photo 1 Placement of a caisson's cutter unit

Caisson guides equipped with guide rollers and jacks were installed on the construction pier in order to prevent tilting during the initial excavation. Tilting during excavation was corrected by adjusting the excavation position of the cutter unit and installing sleeper saddles inside the unit. Sinking of the caisson resulted in a height of -28 mm (standard value ±100 mm), and eccentricity of 45 mm (standard value 50 mm). The maximum daily excavation progress of the shield tunnel was 16.8 m, and three month later the machine reached the caisson arrival chamber. Isolation distance between the internal lining of the chamber and the surface of shield skin plate was approximately 140 mm (Photo 2).

Photo 2 After dismantling the face plate

Railway Bosphorus Tube Crossing, Tunnels and Stations in Istanbul, Turkey

- Marmaray Project Connecting Asia and Europe -

Masahiro **IWANO** ▶ Acting General Manager of Construction Engineering Department,
Civil Engineering Division, Taisei Corporation

Because the railway network in Istanbul is inadequate, passengers and freight must rely on road transport, which has resulted in chronic traffic congestion and atmospheric pollution. The Railway Bosphorus Tube Crossing is being constructed with the objective of relieving traffic congestion by the use of railway, and therefore relieving the associated pollution.

The overall project is referred to as the "Marmaray" project, which is a contraction of "Marmara + Ray (the Turkish word for rail)," and consists of modernizing the railways along the Sea of Marmara, to provide a total of 76 km of railway connected by a tunnel under the strait. In the project, Taisei Corporation and Turkish joint venture partners are contractors for the design and construction of a railway of 13.6 km long in total and related structures in the heart of Istanbul, including the crossing part under the Bosphorus strait. The contract is an EPC (engineering, procurement and construction) contract including track works and mechanical and electrical system for railway operations.

Scope of work

Tunnel has been constructed over 11 km of the work section, by immersed tube, TBM and conventional tunneling (NATM) methods and the cut and cover method have been employed for the construction of stations.

The use of the immersed tube tunneling method in the strait was a contractual condition that was decided in the client's basic plan. The installation water depth reaches 60 m, so this immersed tube tunnel is the deepest in the world for water depth.

TBM tunnel has been constructed in the western end area with mainly sandy soil using one EPB type machine, and the area with mainly rock with four shield type machines, and a total of 19 km will be constructed including the lines in both directions. Between the lines in both directions, connecting tunnels have been constructed at 200 m intervals by the conventional tunneling method for passenger evacuation in an emergency. Also, at two locations on the tunnel, crossover tunnels, in which the lines in the two directions cross over, are provided by conventional tunneling method. To incorporate branch lines in these areas the cross-section was made larger than the TBM tunnel, so these areas were constructed by the conventional tunneling method.

In Istanbul, which includes areas designated as a World Heritage site, an archeological survey is mandatory, and the start of construction had to wait until the Historical Conservation Committee of the Ministry of Culture and Tourism arrives at a conclusion. Therefore archeological surveys were being carried out at all the open excavation areas, which caused a long time delay prior to start of construction.

Besides the tunnel, the contract includes stations at four locations, three of which are underground. Two stations were excavated by the cut and cover method, and one deep underground station (Sirkeci Station) was constructed by a combination of the cut and cover method and the conventional tunneling method.

Status of work

The commencement of project was August 2004, but at a couple of construction sites, excavation works had to await the completion of the archeological survey. As a result, the start of TBM tunneling in European side and the tunneling works in Sirkeci station has been delayed by more than three years. For the time being, Turkish dream came true on October 29th 2013, which is 90th anniversary of republic of Turkey since the limited train operation for passengers started for the 13.6 km railways including Bosphorus Tube Crossing. To complete Marmaray project under severe conditions, many different types of tunneling techniques developed in Japan were extensively used. Success of this project would spread not only a high reputation of Japanese tunneling techniques, but also would provide a new opportunity to extend other similar international projects for underground developments.

Fig. 1 Project overview

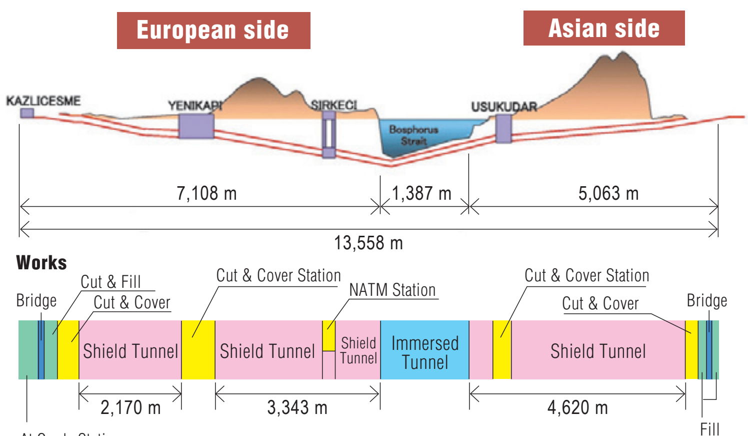


Fig. 2 General plan of Marmaray Project

Excavating Shafts from the Bottom

- Construction of the Branching Shafts of the Midosuji Common Duct by the Upward Shield Tunneling Method -

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Toshio **KOMORI** ▸ Technical Supervisor, Taisei-Goyo Specified Construction Work Consortium for Route 25 Midosuji Common Ditch Construction Work

The Midosuji Common Duct, planned to be constructed in a section about 4 km long from Namba on Midosuji to Umeda under national highway #25, the main street in Osaka, to Umeda, is to accommodate water pipes of 1,500mm in diameter and cables of electric utilities. The Midosuji Common Duct is composed of a main tunnel and branching shafts. Eight branching shafts were constructed: six for power cables, one for water pipes, and one for water pipes and power cables. Seven of these shafts are composed of a branching chamber which is approximately 5 m-high and 15 m-long of box culvert structure near the surface and a shaft approximately 30 m connecting with the tunnel.

Construction site of the branching shafts

Since the branching shafts are located under the Midosuji Road with heavy traffic, work requiring traffic regulation must be enforced only during night time. Osaka municipal subway Midosuji Line also runs nearby. During shaft construction, it was therefore required to minimize impact on the surrounding ground with the subway tracks. Under these conditions, the upward shield tunneling method was selected.

Upward shield tunneling method

This method was used to construct a shield tunnel in the upward direction to the surface from the existing main tunnel. As materials were transported and supplied from inside the main tunnel, the work item to be implemented from the surface during shaft construction was removal of the shield machine only. This feature could significantly reduce surface equipment and shorten the road traffic control period, compared with the conventional excavation from the surface. Constructing shafts by this method exerted less impact on the surrounding ground than the cut-and-cover method.

At the starting point of the upward shield tunnel from the main tunnel, segments for opening made of FFU (Fiber-reinforced Foamed Urethane) were used, which could be directly cut with a cutter of shield machine. This eliminated the necessity of ground improvement such as freezing method at the branch from the main tunnel. This shortened the construction period, reduced construction cost and improved construction safety, compared with face cutting with an auxiliary method such as ground improvement.

The seven shafts include two shafts 3,000 mm in inner diameter, and five 2,750 mm in inner diameter. However, only one shield for the 3,000 mm inner diameter was used, and it was modified to excavate the 2,750 mm inner diameter shafts. This also reduced the construction cost.

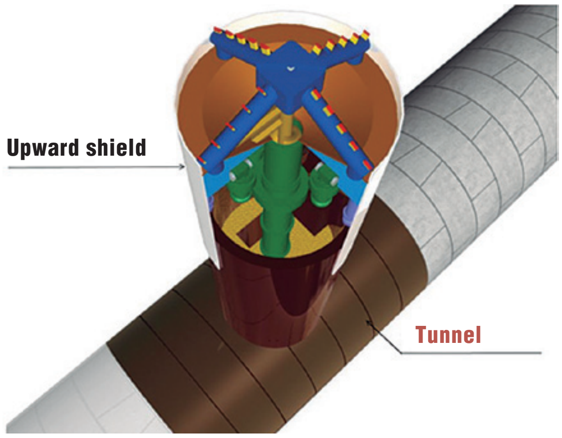

Fig. 1 Upward shield method

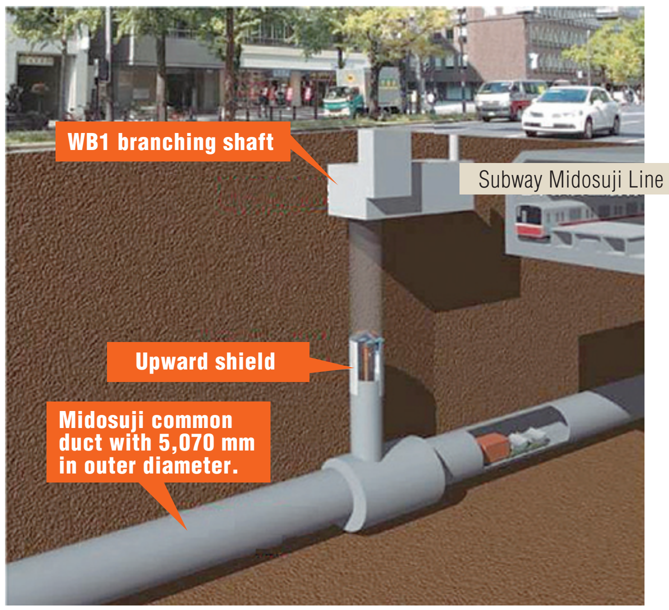

Fig. 2 Branching shaft

Photo Upward shield machine

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New Tunnel Ventilation Technique

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The absorption-type tunnel ventilation system is widely used in mountain tunneling in Japan. It collects dusts generated by excavation and shotcreting at the cutting face.

The ventilation system adopted in the Tanba-ayabe road tunnel of Kyoto-Jukan Expressway is composed of a movable balloon type bulkhead (Fig. 1), electrostatic precipitator (Fig. 2) and air blower (Fig. 3 schematically shows the whole system). Dust produced at the cutting face is contained by the balloon bulkhead and collected by the electrostatic precipitator. The bulkhead and precipitator move as the cutting face advances. The electrostatic precipitator, blower and dust content sensor are connected by a wireless LAN. This ventilation system can be operated automatically by commands from the site office. It has enabled efficient ventilation for tunnels.

Fig. 1 Movable balloon bulkhead (view from the face side)

Fig. 2 Electrostatic precipitator and movable balloon bulkhead (view from the portal side)

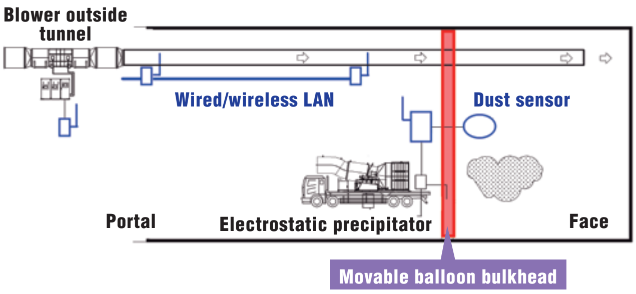

Fig. 3 General diagram of the ventilation system

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Tomographic Survey Utilizing Blasting for Tunnel Excavation

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In the tomographic survey of tunnels, elastic waves are continuously generated from inside the tunnel, which are received and observed at receiving points on the surface, for tomographically analyzing geological status of rock mass. Since survey results are renewed as the tunneling face advances, the survey accuracy is gradually improved.

This survey technique is capable of evaluating distribution and state of faults, fracture zones and hard rocks in more detail than the conventional seismic wave survey methods, i.e., refraction method from the surface and reflection method from the face.

For an elastic wave survey used when tunneling, it is necessary to measure the arrival time of an elastic wave to a precision of a millisecond or less. To apply this tomographic survey to a tunneling site, it has been necessary to connect the oscillation and receiving systems with wires on the surface and near the tunneling face. It has been therefore difficult to apply the technique to a very long tunnel. As a solution for this problem, we have developed a wireless system between oscillation and receiving systems, using highly accurate GPS time signals. (Fig. 1)

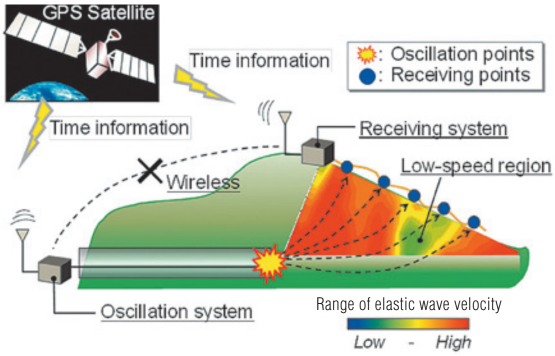

Fig. 1 Schematic diagram of the survey system

The new system makes it possible to use blasting that has very large oscillation energy, in addition to the conventional artificial oscillation sources. As a consequence, the geological status can be accurately surveyed over an extensive area, even in tunnels with a large overburden, a task that has been difficult using previous techniques. (Fig. 2)

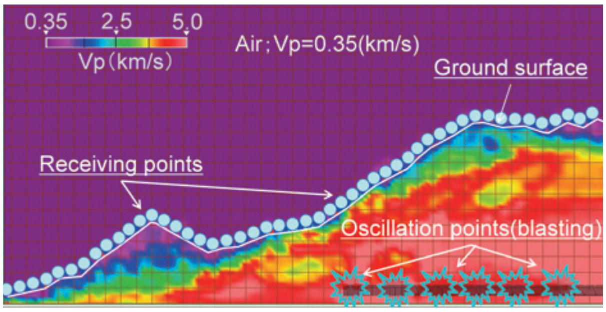

Fig. 2 Analysis results of tunnel tomography

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Standardization of Medium-fluidity Lining Concrete in Expressway Tunnels

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Density of lining concrete for mountain tunneling, especially in the crown, has tended to be low due to insufficient compacting. As a solution to this problem, medium fluidity lining concrete mixed with coal ash and stone powder was developed. The medium fluidity concrete has a suitable fluidity, with high resistance against material separation. By using a form vibrator (Photo 1) as an auxiliary device, excellent filling capability and density are obtained. However, because coal ash and stone powder are not easily obtained and silos to store these materials are not readily available, districts capable of using medium fluidity concrete with coal ash and stone power have been limited. To cope with this problem, a study was conducted to determine whether it is possible to make medium fluidity lining concrete using air entraining superplasticizer (prepared with viscosity improving polymer). Through verification of properties and quality of this type of concrete, we concluded that it is applicable to construction of expressway tunnels. In July 2013, a standard specification was prepared for medium fluidity lining concrete using coal ash, stone powder and air entraining superplasticizer (prepared with viscosity improving polymer (Table 1). Guidelines were established for enabling use of this type of concrete for expressway tunnels as a standard material.

Photo 1 Form vibrator installed

Material	Powder	Viscosity improver
Compressive strength at 28 days (N/mm^2)	24	
Max.size of coarse aggregate (mm)	20/25	
Slump and slump flow (cm)	21 +/- 2.5 35 to 50	
Vibration deformation test (cm)	Slump flow spreading after vibration for 10 seconds. 10 +/- 3 When spreading concrete after vibration, there should be no exposed coarse aggregate at the center, and no band of paste or free water 2 cm or larger in the surrounding.	
U shape filling height (without obstacle) (mm)	280 or more	
Air content (%)	4.5 +/- 1.5	
Cement type	Ordinary Portland cement (With coal ash, blast-furnace cement type B cannot be used.	Ordinary Portland cement, blast-furnace cement type B
Minimum specific cement content (kg/m^3)	270	320
Specific water content	Coal ash 180 or less Stone powder 175 or less	175 or less
Max. chloride content (Cl-) (g/m^3)	300	300

Table 1 Standard specification for mix design of medium fluidity lining concrete (draft)

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Low-frequency Blasting Noise Reducer for Tunnel Construction

– Blast Silencer®–

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Excavation with blasting instantaneously produces extremely large energy over an extensive area, causing significant impact on the environment. In particular, low frequency components of blasting noise may vibrate windows of residences several hundred meters away from the tunneling site. Since low frequency components attenuate very little in the tunnel, some special measures to reduce the noise are needed even if the face became far from the tunnel portal.

Conventional noise reduction measures are to install several massive soundproof doors of concrete at the portal to contain explosion noise in the tunnel. However, the noise reducing effect for low frequency components is small, around 5 dB.

The silencer (fig. 1) introduced here utilizes resonance of an acoustic tube to produce reflective inverted sound (antiphase sound) of the explosion noise (Fig. 2). By making low frequency sound passing through the opening of the silencer to interfere with the antiphase reflective sound (Fig. 3), attenuation of about 15 dB is achieved, reducing impact on the environment to a large extent.

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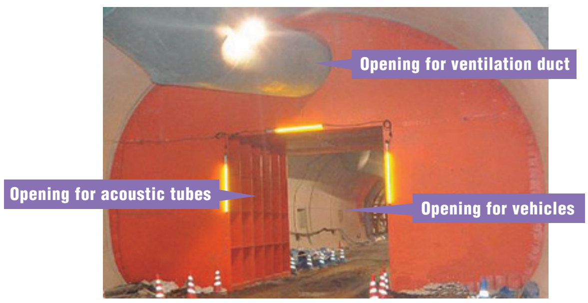

Fig. 1 Blast Silencer® installed

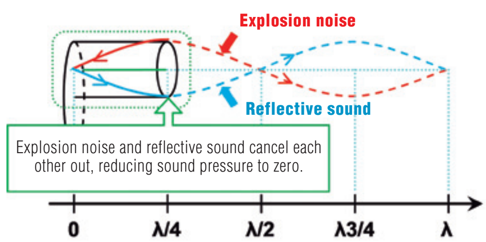

Fig. 2 Principle of noise cancellation

Fig. 3 Schematic diagram of the silencer