Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2018

JAPAN TUNNELLING ASSOCIATION

PREFACE

I feel really privileged to be given this opportunity to address tunnel engineers throughout the world on the occasion of the publishing of the 2018 edition of Tunneling Activities in Japan, a Japan Tunneling Association (JTA)'s biennial publication.

Despite the fact that in recent years tunnel construction projects in Japan are on the downturn, our country remains one of outstanding global leaders in terms of tunnel construction volume.

Increase in tunnel length and expansion of tunnel cross section are two specific features in mountain tunnels of recent tunnel projects in Japan. The advancement in tunneling technologies in recent years has made it possible to construct economically long tunnels and large section tunnels in the complex and wide-ranging ground conditions in Japan. As a result, it has become possible to choose the shortest routes and higher standards in railway and road projects.

In construction of urban tunnels, on the other hand, there are many cases in which construction work is implemented in the proximity of existing structures in areas where there is a convergence of underground structures such as subways, utility lines, etc. In addition, urban tunnels must be constructed to meet strict demands for reducing the impact on the surrounding environment. These factors have fueled the progress in the development of design and construction methods and shield machines that can fulfill the specific requirements for construction of urban tunnels.

Based on such recent specific examples, this booklet presents a selection of some typical examples representative of the numerous tunnel projects and technological developments in Japan. I will be pleased if these articles prove useful for tunnel engineers around the world.

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President
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Cover Photograph by
Shin Matsumoto
"Tunnel Tour"
An-eigawa Tunnel, Toyota City

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Innovations in Technology

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Streamlining the Boring of an Urban Railway Tunnel by Using Two Methods Jointly, SENS and Shield Tunneling

- Joint through service between Sagami Railway and Tokyu Line, Hazawa Tunnel

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The Hazawa Tunnel is a double track tunnel which is located about 25 km from the Tokyo metropolitan center as part of a new 3,499 m-long line directly connecting two urban railways, the Sagami Railway and the Tokyu line. From an economic viewpoint, the structure of the support lining is designed to use shield method type segments at each of the two portal sections, while the lining of the mid-section is constructed with SENS-based cast-in place concrete.

1. Characteristics of SENS

The SENS (Shield tunneling method, Extruded concrete lining, NATM system) uses a closed type shied machine for excavation, and constructs the primary lining with cast-in place concrete.

The steps for tunneling using the SENS are as follows. First, the shield machine is put in operation for tunneling, while at the same time, concrete is placed under pressure from the tail of the shield machine to keep the in-situ ground sturdy, prior to placement of the primary lining. The second step is to confirm the reliability of the primary lining, and finish the secondary lining after checking that displacement has completed. This step is repeated until this project is completed. In the SENS, the primary concrete lining has a unique role as a support equivalent to that given in NATM.

In situations where the ground surrounding the tunnel is barely able to remain intact during excavation, the SENS method is superior in safety and workability over the NATM method, which requires various auxiliary methods for tunneling, whereas the SENS method is more advantageous than the shield method because it does not place high-cost segments.

2. Study of the application of SENS to the Hazawa Tunnel

The ground through which the tunnel is to be excavated belonged to the Kazusa Group, as in the case of the Nishiya Tunnel on the Sagami Railway - JR direct line which was bored by SENS prior to this project. Although the groundwater level was higher than for the Nishiya Tunnel, SENS-based excavation was determined to be possible. At the starting and arrival portal sections, this tunnel runs close to the viaducts of a trunk road, and at some places, it crosses or runs parallel with said road. Considering these conditions, we studied the possible impact of the project on the neighboring structures in advance and validated the resistance of the primary lining. From the results of the study, it was predicted that the subsidence of the road viaduct piers corresponding in location to the portion of on-site lining placement, might exceed the reference control level of the starting portal section, but at the portion where the segments were placed be less than said level.

It was also revealed that at the arrival section, there was a distance of only 1.8 m from the lower end of the viaduct to the top of the lining, and it was predicted under such conditions that the lining placed by SENS on site may produce a stress larger than the resistance, but in the section with segment the stress will be lower than the allowance. From the reason above, it was decided that at both extremities of the tunnel, the lining be constructed with segments, and for the remainder of the tunnel, SENS type lining could be used for reasons of economy in the same manner as the construction of the Nishiya Tunnel. For this construction project employing two different methods, we decided to resort to a single shield tunneling machine. This is the first attempt using a single shield machine to change over from the shield excavation to SENS's for the construction of a tunnel.

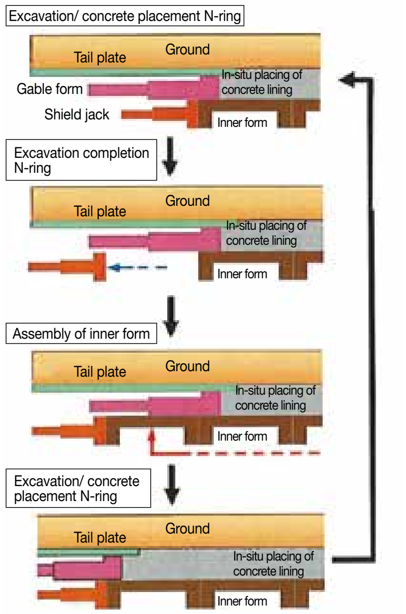

Fig. 1 SENS excavation and placement cycle of primary lining

3. Construction progress

Preliminary construction of the Hazawa Tunnel was completed in March 2016, and then main construction was started in July 2016. The project had already been finished for a 502.8 m section of segment placement at the starting portal section, and in September 2016, arrived at the point to switch from shield method to SENS. The equipment of the shield machine has been changed for SENS tunneling, and since December 2016, SENS excavation is under way.

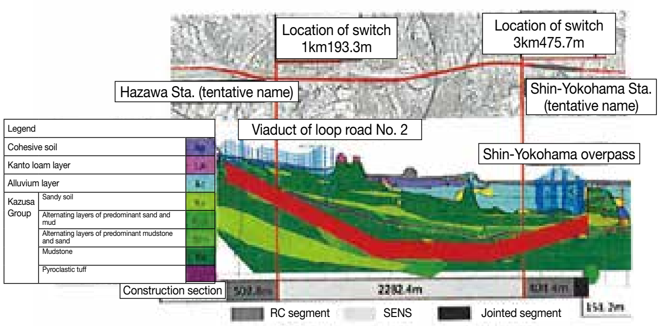

Fig. 2 Longitudinal geology profile of Hazawa Tunnel

Heaving of roadbed Countermeasures in Squeezing Ground

– The Case of Tawarazaka Tunnel on the Kyushu Shinkansen (West Kyushu) –

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In mountain tunnels, there are cases in which heaving of roadbed occurs in the invert after the tunnel is completed, necessitating appropriate countermeasures. After the tunnel is put into operation, however, construction measures to deal with heaving of roadbed become difficult and pose a significant burden from an economic perspective. Yet, currently it is difficult to predict the occurrence of heaving of roadbed at the time of excavation and to select appropriate countermeasures.

1. Construction conditions of the Tawarazaka Tunnel

The Tawarazaka Tunnel on the Kyushu Shinkansen Line was built using the mountain tunneling method as a double track railway tunnel. The geology consists mainly of Paleogenic mudstone intercalated with tuff. The strength of the mudstone is approximately 10 MPa, and there are numerous latent cracks. The results of the rock slaking test exceeded the index that suggests high probability for occurrence of heaving of roadbed. Expansion of the internal space convergence that accompanies the increase in ground plasticity, and negative convergence trends were also confirmed. These symptoms prompted the implementation of early closure using a primary invert with the objective of limiting the convergence and achieving stability for the tunnel and the surrounding ground. In the locations where the convergence was particularly large, highly rigid supports were installed in order to restrain convergence during construction (Fig. 1).

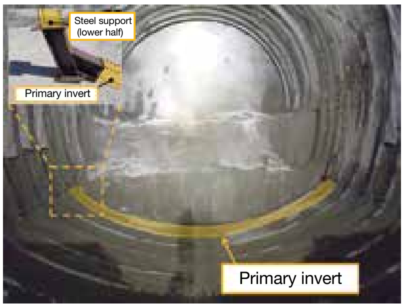

Fig. 1 Construction of primary inverts

2. Examination based on numerical analysis

The convergence in the section, in which early closure was implemented with primary inverts, was evaluated from start to completion of construction using a systematic evaluation method. The analytical model was 60 m in the vertical direction, 40 m in the transverse direction, and the total length of the tunnel was 90 m. Excavation was represented using methods for three-dimensional successive excavation, and the model assumed that the heaving of roadbed after completion of the tunnel will involve decline in the shear strength in line with the fracture proximity (loosening) of the ground (Fig. 2). Based on the excavation data, the author implemented reproducible analysis of the tunnel excavation and made a prognosis about the deformation of the tunnel ten years after completion. The results indicated that the convergence after completion was 3.6 mm during the ten years after completion, and the heaving of roadbed was 1 mm for the same period. These results indicated that it is possible to restrict convergence to an extremely low level (Fig. 3).

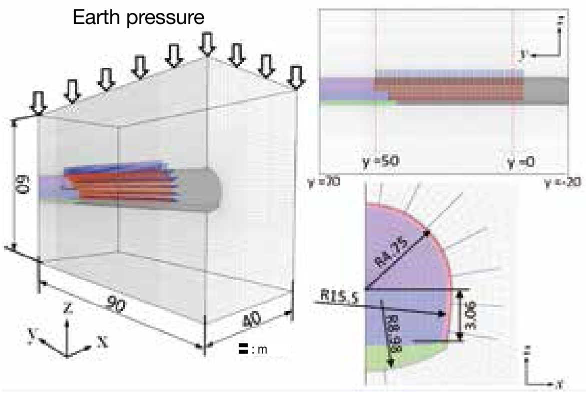

Fig. 2 Analysis model diagrams

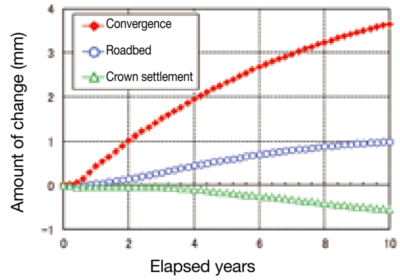

Fig. 3 Relation between convergence and the number of years passed after completion

3. Construction and measurement results

In the section where primary inverts were constructed, measuring devices were installed in the concrete of primary invert to measure the stress, which has an impact over the long term (Fig. 4). Shotcrete is affected by stress immediately after excavation, but stress was maintained below the values for design strength (18 N/mm²), and it is believed that the placed shotcrete continues working as a support component of sufficient resistance. It was confirmed that although stress affects invert concrete and lining concrete, overall this stress was low.

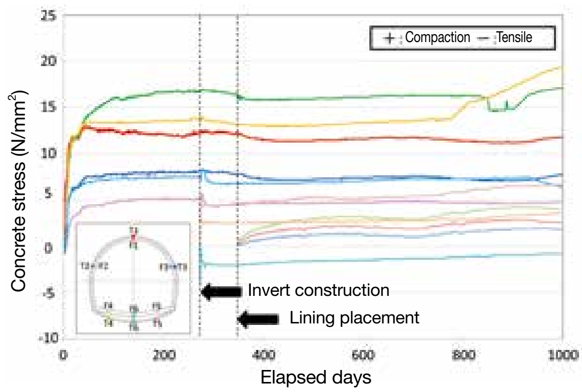

Fig. 4 Long-term measurement of concrete stress

3

Construction of a shield tunnel under an operating railway track

- Quadruple track construction on the Odakyu Line -

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Masaki ITO ▶ General Manager, Odakyu Electric Railway Co., Ltd.

The current traffic system in this area has been plagued by chronically poor traffic flow. To alleviate traffic congestion at ground-level crossings, this project is aimed at building a new railway traffic configuration. In order to drastically improve transportation services changing the current double tracks to quadruple tracks, we employed continuous grade separation between road and railway.

1. Shield tunneling

The shield machine commenced excavation from the starting shaft and continued boring the tunnel under an existing railway track (under about 10 to 17 meters overburden). When arriving at the U-turn shaft, it made a U turn (see Photo 1) to excavate another tunnel going toward the original starting shaft. Consequently, each of the two tunnels thus provided had 8.1 meters in diameter and 645 meters in length.
These shield tunnels paralleled each other under a densely built-up urban area of housing, and after being completed, were extended laterally to build a station building. Then, the conventional two lines were relocated underground. Then, the upper section of the shield tunnel was excavated and remodeled into a box type tunnel frame with a cut and cover method.

2. Enlargement of the shield tunnel

At the section of the station building, approximately 180 meters of the existing railway track were temporarily underpinned with pile supports; the ground immediately under the station building was excavated and the shield tunnels were enlarged by cutting and then integrated into the RC frame. During the enlargement of the shield tunnels, construction progressed smoothly by providing deformation prevention measures to control resulting stress in segments (Figure 1).

Photo 1 U-turning of shield machine

Photo 2 Enlargement of the space by cutting segments

The connecting points between the RC frame and steel segments were checked through a prior demonstration experiment, for their behavior and integrity to determine the desired structure.

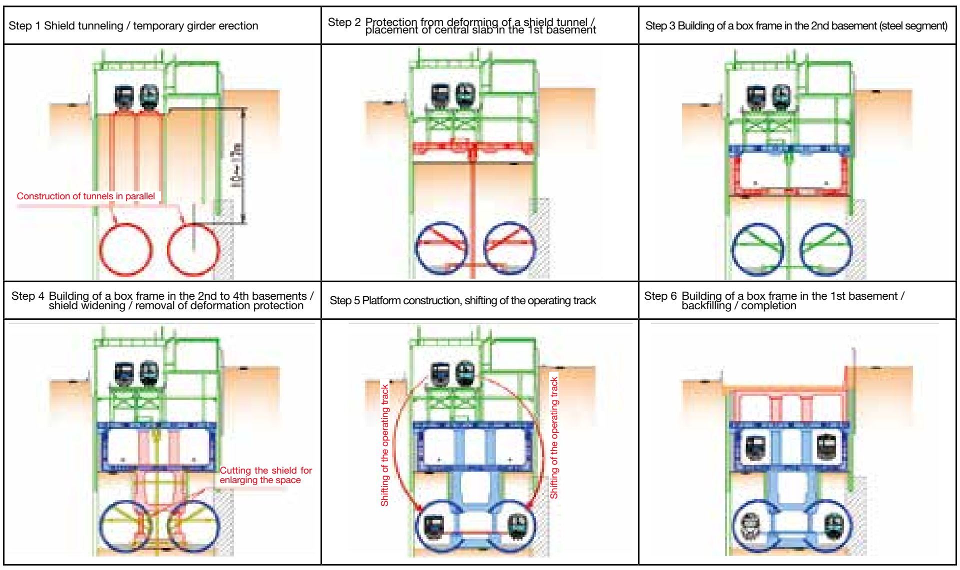

Fig. 1 Construction phase flow diagram

Improvement Project for Kiba Station on the Tozai Subway Line

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1. Summary of the project

Currently, Tokyo Metro is operating 9 lines in the central area of Tokyo, totaling approximately 200 kilometers of subway. This project is one example of subway remodeling, a project which is now in progress at Kiba Station on the Tozai Line to improve services for passengers.

The Tozai Line is a subway route crossing the metropolitan area of Tokyo from east to west. Since opening, the areas along the line have developed at a fast pace, and passengers using this line have increased accordingly. But with chronic delays in train operation, there was a growing danger that passengers might fall from the platform onto railways. For this reason, committing to improvement of the safety level on the Tozai Line , and as part of this effort, worked out a plan to improve Kiba Station.

2. Overview of Kiba Station and problems for immediate solution

Kiba Station is the first station which was constructed in a shield tunnel in Japan (inner diameter 7,240 mm, outer diameter 7,740 mm, segment width 800 mm, using ductile segments). The station has a total length of 220 meters, bored in a thick, soft diluvial clay formation 30 meters in depth. At both ends of the station's length, there is a shaft which was constructed by sinking caissons below the road.

Currently, Kiba Station has two problems. First, flow lines of passengers are complicated and intertwined because the platform is narrow and elevators and escalators are provided only where shafts exist, and secondly, since passengers currently tend to concentrate at both ends of the platform, waiting queues of passengers have difficulty approaching the train they are going to ride.

For these reasons, planning to widen the platform and provide additional elevators and escalators (Fig. 1) in order to provide a safer and less congested environment for passengers in the area between the platform and the ticket gate.

3. Construction plan

Kiba Station is a station built in a shield tunnel. The unique features of this project which was the first of its type in the world, included a process of creating a new cavity to allow the platform to be widened by removing the existing shield tunnel walls, without suspending operation of trains.

For this purpose, the process is divided into two steps; the first is to build a box culvert with three layers and three spans in a new space which is created by demolishing and widening the tunnel over an 80 m section from the east, while keeping trains running, and the second to remove the segments (Figs. 2 and 3). Then in order to provide sufficient transport capacity, two escalators are installed inside the box culvert.

Considering the construction site was in extremely soft ground around Kiba Station, the authors first constructed underground girders to improve the in-situ ground, and used an inverted lining method, using the main structure of tunnel as a key support to build an underground cast-in-site diaphragm wall.

The ground underneath the existing segments, first underpinned for safety with the support of an already improved ground structure, was to be excavated into trenches.

The project is currently underway. Making full use of the technology available so far, we have done our best to direct this project successfully as a high quality innovative effort, in a manner to meet the needs of the times.

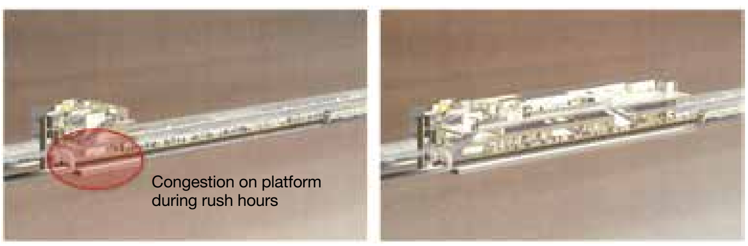

Fig. 1 Current status and improved status

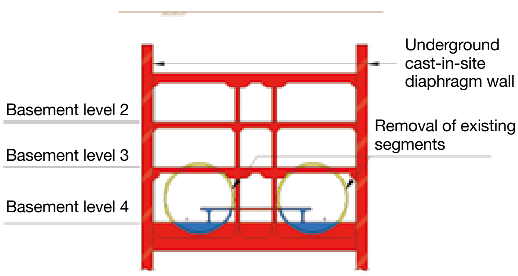

Fig. 2 Sectional drawing of plan

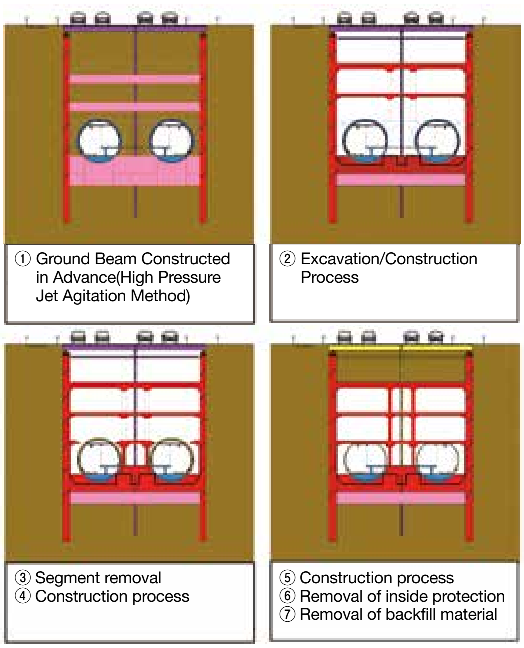

Fig. 3 Cross section

Construction of an underground passage with small cross-section under railroad tracks by covering with steel plates

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Motoaki KURISU ► Manager, Underground & Foundation Technology Department, Civil Engineering Division, Tekken Corporation

This project built a pedestrian underground passage after the removal of the Yabe Grade Crossing at Yabe Station on the JR Yokohama Line. The underground passage directly below the JR Yokohama Line is a single-level single-span box culvert with the following dimensions: width 4.8 m, height 3.8 m, and length 14.5 m. The ground in the construction area is composed of a highly self-standing formation of cohesive soil with an N-value of 4 to 5, and the groundwater level is beneath the level of the planned section (Fig. 1). Construction methods were compared and the COMPASS (COMPact Support Structure) method, an outstanding method in terms of time required for construction, cost and safety, was selected as the construction method for this project.

(1) Construction method overview

The COMPASS method is a non-open-cut method for building small cross-section structures under railway tracks and roads. In this method, guide pipes that contain earth-cutting wires are installed. Next, the ground in the outer periphery of the planned structure is cut with the wires, and then steel plates are inserted immediately. After that, the ground enclosed with steel plates is excavated by sequentially connecting precast boxes behind a specific cutting unit to form a box culvert.

In the COMPASS method, the ground is cut with wires and the supporting steel plates are inserted simultaneously, so the construction is possible in all kinds of soil, has little impact on the ground surface, and the excavation of the ground enclosed within the steel plates poses almost no risk of ground subsidence.

(2) Construction results

This project was constructed with shallow earth cover (approximately 1.2 m) directly under the JR Yokohama Line, which is located in a metropolitan area, so risk control measures to deal with railroad track deformation were considered for each construction step. Operations that were likely to affect train operation were scheduled at night. During construction, displacement meters were installed at all times in order to monitor the effect of construction on the railroad tracks for continuous track measurement.

No vertical displacement was recorded due to construction exceeding a control value of 7 mm (40% of the value that requires immediate termination of construction) during the insertion of upper floor slab protection steel plates located directly under the railroad tracks. The vertical displacement during the precast box excavation was negligible as seen during the insertion of protection steel plates for the upper floor slab.

As a result of employing the COMPASS method and rigorous risk control measures, no deformations likely to affect train scheduling occurred throughout the construction period, and the project was successfully completed.

Photo 1 Insertion of protective steel plates

Photo 2 Completion of construction of precast box

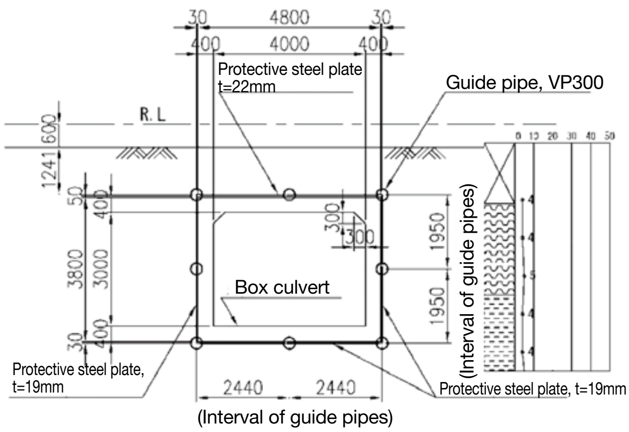

Fig.1 Cross-section diagram of the structure

Ultra-large cross section tunneling by widening from inside - Isshiki Tunnel, Chubu Odan Expressway -

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Kofu River and National Highway Office, Kanto Regional Development Bureau,
Ministry of Land, Infrastructure, Transportation and Tourism

The Chubu Odan Expressway has total a length of 132 km, linking key expressways crossing the central part of the Japanese archipelago. Isshiki tunnel is a road tunnel with a single lane in each direction for two-way traffic, located west of Mt. Fuji, the highest mountain in Japan. This tunnel project is a segment of 685 meters on the north side, part of the total length of 1,275 meters.

1. Boring a working drift to shorten the work process drastically

In this project, since a new interchange was to be built, the amount of removal earth at the portal was approximately doubled to 280,000 m^3 in comparison with the initial estimate, and the construction period also was required to be greatly reduced. To cope with this problem, a 240 m-long working drift was constructed to proceed the excavation of main tunnel and soil removal forward in parallel. We were able to complete construction two years earlier than planned (Fig. 1).

2. Enlargement of the main tunnel to an ultra-large cross section

The portal of this tunnel is designed to consist of four lanes for merging and branching, so the soil removal to be excavated there amounts to approximately 200 m^2 in cross section, the largest scale ever attempted in Japan (Fig. 2). Considering these conditions, handling excavation starting from the working drift whose area of excavation section would be about 60 m^2 and reaching an ultra-large section of the main tunnel was challenging.
The portal was initially planned to be bored with a regular side drifting method for a large boring section. Referring to the boring survey where samples were taken from places of excavation to determine actual physical properties, and with the two dimensional FEM analysis, it was possible to use a multi-staged bench cutting method, which was more economical and superior in performance (Fig. 3). Based on this method, excavation was started by boring a working drift which has a face area of about 60 m^2 with a single center circle shape, and gradually was extended to form the intended upper half of about 100 m^2 with a large aspect ratio, by altering the excavation cross section through construction of several benches (Fig. 4 1) to 2)).
After the upper half was reached, the face was excavated following a very flat geometry, using a long size steel forepiling technique while minutely monitoring the displacement that took place up to the portal (Fig.4 (3), Photo -1). Then, as excavation was reversed, the heading was integrated into the section of the main tunnel, and then the lower half was excavated (Fig.4)

3. Breakthrough of the tunnel by cutting at the tunnel portal

By providing a working drift to allow the main tunnel to be bored in an easier way, the portal was opened and penetrated by an open-cutting technique with few precedents in Japan (Photo 2). At this point, the load acting on the tunnel was to be released, under which the tunnel would be likely to be deformed. To cope with this problem, we conducted a 3 dimensional FEM analysis to predict stress and deformation, and by confirming the safety of supports, excavated the portal section by cutting. As a result, although the crown of the tunnel suffered a slight upward displacement due to unloading on the earth covering, no remarkable deformation on the supports was recorded, and we successfully completed soil removal safely.

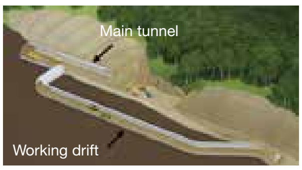

Fig. 1 Bird's view of the tunnel

Fig. 2 Rendering of the tunnel portal

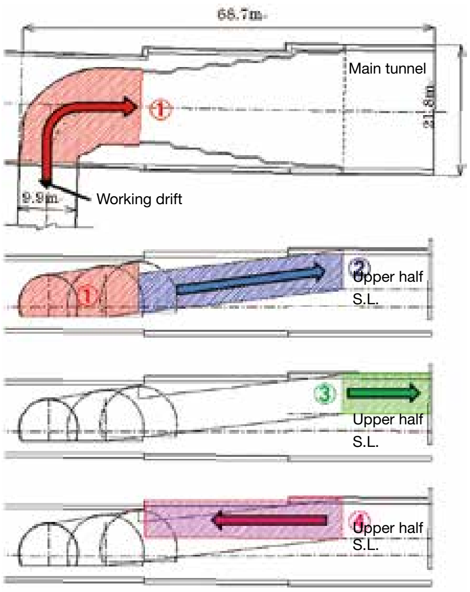

Fig. 3 Multi-staged bench cutting method

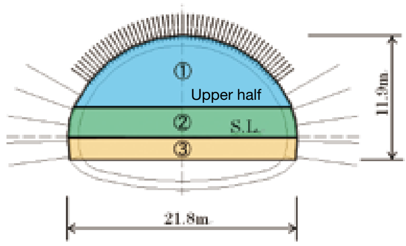

Fig. 4 Schematic drawing of main tunnel widening process

Photo 1 Tunnel face of upper half

Photo 2 Penetration of tunnel portal with earthmoving

Tunnel drilling in weak ground using the Early Cross Section Closure Method

– Chubu Odan Expressway, Hachinoshiri Tunnel –

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Yoshiaki MASHIMO ► Director, Civil Engineering Department, Nagoya Regional Branch, Shimizu Corporation

1. Project overview

Photo 1 Tunnel excavation

The Hachinoshiri Tunnel is a mountain tunnel on the Chubu Odan Expressway, an expressway that crosses Honshu. It is located at the foot of Mount Fuji, approximately 100 km west of Tokyo. The tunnel has a total length of 2,469 m and excavation face of 82 km^2. The excavation method was full-face NATM using a large-scale tunneling machine (Road Header 330 kw [Photo 1]), and a belt conveyer system was used for mucking. The tunnel was excavated between August 2011 and August 2015, and was opened for traffic in March 2017.

2. Geological conditions

The geology of the project site was composed of a gravel layer, landslide colluvial soil, mudstone, basaltic lava, and basaltic pyroclastic rock. Landslide morphology was confirmed in the vicinity of the starting shaft (the shaft in the northern end), and it was also projected that construction would encounter weak mudstone ground with uniaxial compressive strength of around 0.1 N/mm^2 (competence factor $qu/\gamma H<0.1$) in the central area of the tunnel. Also, there were concerns over possible deformation, breakdown or excessive displacement of support materials in construction work using standard support patterns for 22% of the full length of the tunnel. Overall, the geological conditions made ensuring tunnel stability a difficult task (Fig. 1).

3. Tunnel stabilization methods

Below is a list of the construction technologies adopted as tunnel stabilization measures in weak ground for this tunnel construction project.

▷ Long span steel pipe forepiling as a measure to reinforce the face crown, as well as long-span face bolts and curved face as a measure to stabilize the face (a method to improve the autonomy of the face with arches by excavating in a spherical shape)

▷ Full face Early Cross Section Closure Method adopted in order to interrupt any convergence at an early stage (invert closure at 3-6 m behind the face)

▷ Improving the strength of supports ⇒ Installation of steel arch supports H-200, high-strength shotcrete t=300 (design strength 36 N/mm^2), high strength rock bolts L=4 m (pulling resistance 170 kN)

▷ Three-dimensional measurement control using 3D scanners with the objective of appropriately assessing face shape and improving the efficiency of the three-dimensional behavior monitoring

4. Occurrence of deformation during construction and countermeasures

During construction in the area composed of weak mudstone, the project encountered unexpected squeezing-type ground pressure equivalent to approximately 2 MP, leading to the occurrence of convergence of up to 675 mm. To deal with this issue, the following measures were implemented in order to ensure durability of supports, and eventually structural soundness of the tunnel was restored by re-excavating the tunnel and re-building the supports in a 125 m-long section.

▷ Significant improvement of the support strength through installation of double-tier supports (steel arch supports: primary H-250 + secondary H-200, shotcrete primary t=300, secondary t=200)【Fig. 2】

▷ Upgrading rock bolts to ultra-high strength bolts (pulling resistance 290 kN)

▷ Adding steel supports to the invert sections, and reducing the size of curvature to the same extent as the arch sections and making the shape of the tunnel as close as possible to a circle in order to suppress the occurrence of a bending moment.

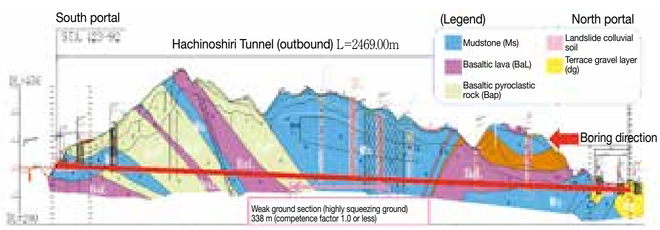

Fig. 1 Geological profile

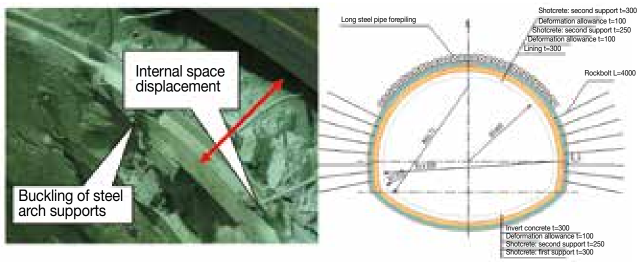

Fig. 2 Tunnel profile (double-tier supports)

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The Largest Shield Tunnel Project in Japan

– Tomei-North section of the main tunnel, Tokyo Outer Ring Road

Takashi SHIDOJI ► Director, Tokyo Outer Ring Road Construction Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

Kenji KATO ► Director, Tokyo Outer Ring Road Construction Office, Kanto Branch, East Nippon Expressway Co., Ltd.

Junichi SUGII ► Tokyo Construction Office, Tokyo Branch, Central Nippon Expressway Co., Ltd.

Introduction

The Tokyo Outer Ring Road (connecting the Kan-etsu and Tomei expressways) is a 6-lane underground expressway around 16.2 km long, which is to be bored underneath urbanizing Tokyo. The project will construct two tunnels, each having 3 lanes in each direction, by using a shield machine with a diameter of around 16 m, the largest in Japan. Tunneling along the route is required to overcome severe conditions: large cross-section, long distance and excavation at high speed. Therefore, the tunnel will be excavated from two directions, north and south, so that in the event of unforeseen problems, one of the tunnels could be extended since they are coming at each other from opposite directions.
For the placement of orders for the project, there are two ownerships involved, Central Nippon Expressway Co., Ltd. for the northbound tunnel and East Nippon Expressway Co., Ltd. for the southbound tunnel.
Since each route is divided into two segments, there are a total of four segments which are excavated by shield machines (Fig.1), and consequently four shield machines are required. This paper reports the characteristics of the shield machine used for the southern sections and the progress of tunneling.

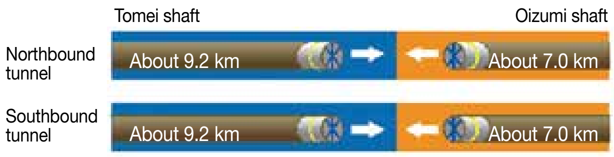

Fig. 1 Segments for outsourcing of construction

1. Characteristics of the shield machine

The shield machine going north weighs about 3,700 tons, and the cutting head is divided into two sections, outer and inner circumferences. This configuration, named "the double cutting system" (Fig. 2), allows the face within the inner circumference for the removal of the core to be excavated first, resulting in approximately 30% higher efficiency in power consumption than tunneling by a single driving system.

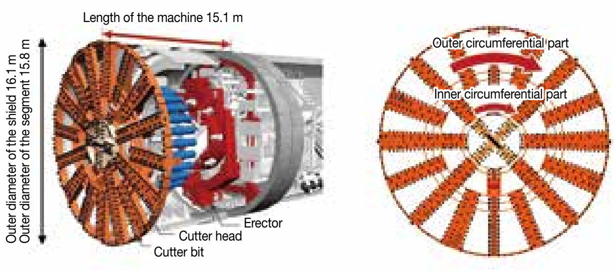

Fig. 2 Shield machine for the northbound

The south-bound machine has a weight of approximately 4,000 tons, with 242 pre-cutting bits ("relay bits") (Fig.3) on the cutting head which are able to be replaced a number of times. The system of the cutter head is structured so that a worker is able to enter behind the cutter spokes and safely insert new bits to replace the old ones.

Fig. 3 Shield machine for the southbound

2. Conditions of the construction project

At the current stage, the starting shaft for the tunnel has been completed, and the shield machine, after being assembled, has continuously excavated since February 2017 (Fig. 4).

Fig. 4 Assembling of the cutter and view inside the tunnel

Tunneling is to proceed at a slow speed of approximately 3.2 meters per day for the initial excavation segment, but at the peak, the speed will reach about 30 meters per day. For the excavation, we will use a belt scale to weigh the muck, and a laser scanner to measure the volume of muck, monitoring various measurements in the tunnel and on the surface to improve project safely.

Construction of a road tunnel of the world's largest class directly beneath a railway station using the R&C Method

—Underpass construction project on the Tokyo Outer Ring Road—

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Daisuke MORIMOTO ► Managing Engineer, Tokyo Civil Engineering Division, Shimizu Corporation

1. Project overview

This project will construct a double-layer four-section box culvert under Sugano Station where the Tokyo Outer Ring Road crosses the Keisei Main Line. The R&C Method was used in construction.

The R&C Method is a method for construction of underground structures by replacing a rectangular section box-type roof beneath the ground installed as a shield to protect the railway tracks with a box culvert built at the starting shaft. The box culvert in this project is composed of steel segments and has the following dimensions: height 18.4 m, width 43.8 m, and total length 37.4 m (9.35 m per box multiplied by four boxes). The cross-section size of the culvert is the largest class in the history of application of the R&C method.

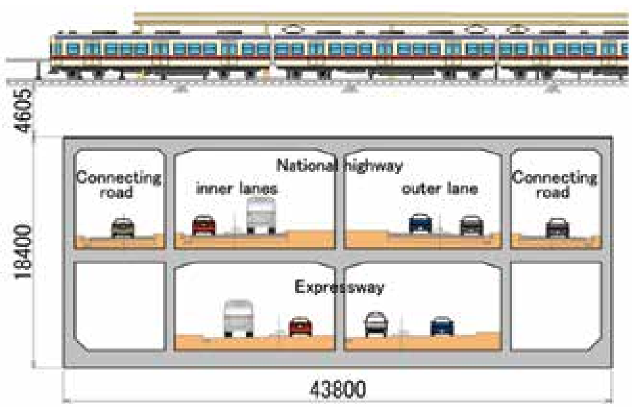


Fig. 1 Cross section view of the box culvert

2. Face stabilization measures

The R&C method is an open-face shield method. Normally, the height of most box culverts built using this method is less than 10 m, and usually the face has one stage. In this project, because of the size, there were various issues to be taken into consideration including measures to deal with deformation of the railway tracks and maintaining stability of the face. To solve these issues, a pipe roof was installed horizontally in the mid-section, and a structure with a two-stage face was adopted (Fig. 2). Furthermore, measures to reinforce the ground by chemical grouting and to boost the rigidity of the box roof were combined, and as a result the deformation of the railway tracks was reduced and the safety of construction was improved.

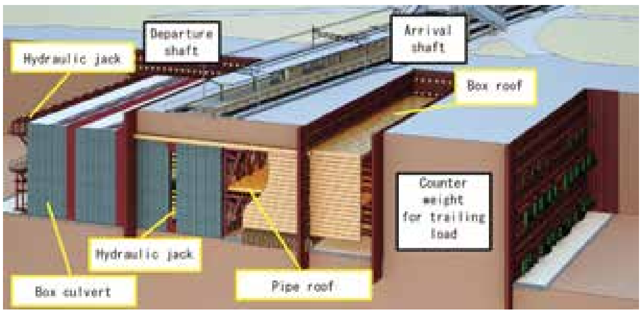


Fig. 2 Box culvert traction status diagram

3. Measurement of stress intensity inside the box culvert and guaranteeing precision of traction

In this project, steel segments were utilized in the box culvert with the objective of shortening processes and reducing labor for on-site operations. Consequently, this required more risk assessment than for the traditional R&C Method, which has a longer history of usage. That is why three-dimensional FEM analysis was used in advance to clarify the out-of-plane load caused by jack thrust, and the relative displacement allowance of the box culvert was determined based on the stress intensity that occurred in the segments and bolts. In the execution of box culvert traction, the shield jacks were controlled based on the measurement values obtained from strain gauges installed inside the box culvert and laser distance meters that monitor the location and position of the box culvert. Also, intensive computerized control was utilized for some of the jacks in the culvert traction.

4. Track measurement

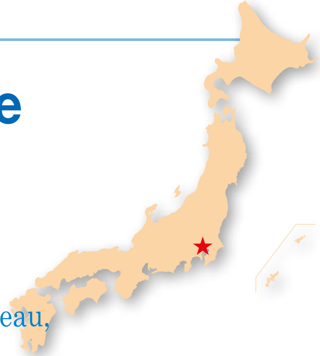
The scope of impact of this project on the railway tracks extended approximately 120 m. Control values were set for all facilities within the tracks, and measured automatically using an automatic tracking total station. The railway track was checked regularly and at suitable intervals throughout all stages of the construction process, ensuring safe operation of the tracks open for traffic.

5. Conclusion

The face was excavated during the day, while box culvert traction was generally conducted at night when the tracks were closed for traffic and one-time traction was set at about 20 cm.

The box culvert traction had no significant impact on the tracks, and both internal stress within the box culvert and traction force were maintained within the projected scope until successful completion of construction (Fig. 3)

Fig. 3 Completion of the box culvert traction



World's First Application of Underground Large Diameter Tunnel Widening Technology Using Enlargement Shield Tunneling Machine

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Metropolitan Expressway Route K7, Yokohama North Line, is an expressway which links the port area and the inland area of Yokohama City over a total length of approximately 8.2 km. It was opened for traffic in March 2017. In order to minimize the number of houses to be removed and to preserve the environment in the surrounding area, Yokohama North Line was designed and built as a tunnel structure under the residential area covering approximately 70% of the total length equating to around 5.9 km, out of which around 5.5 km was built as two parallel tunnels of an external diameter ϕ 12.3 m using two large diameter earth pressure balanced TBMs.

After completing the construction of the above parallel tunnels, tunnel junctions connecting four ramps were further constructed to Yokohama North Line at the mid-point of its route where the tunnel cross-section was enlarged by a trench less construction method without using the conventional cut and cover method. This was the first project in the world in which the tunnel widening under the residential area was attempted and achieved.

1. Summary of the underground tunnel enlargement technology

The surface area, where the tunnel widening was implemented, was densely packed with houses, and the overburden was of great depth ranging from 28 m to 54 m. This made construction works using the open cut method difficult, so it was decided to use the trench less method that enlarges the structure from the segmentally lined tunnel. Although the geology was relatively good, and consisted mainly of Kazusa layers, there was a possibility of triggering quicksand and consolidation settlement in case groundwater flooded from aquifers interlaid in Kazusa layers. That is why we employed new technologies, to widen the tunnel underground in the most reliable and safe manner from the viewpoint of reducing impact on the surrounding environment, i.e. a combination of two approaches; one was a new type of TBM (Enlargement Shield Tunneling Machine/ESTM) designed to widen the tunnel diameter and the other is a conventional pipe roofing technique (Large Diameter Pipe Roofing/LDPR). The construction steps are summarized as below.

① In order to split the underground enlargement section (a total length of 150m – 220m) into multiple blocks, a groundwater cut-off wall was built by injecting chemical grout at the starting, intermediate and terminal points of the section for enlargement.
② At the starting point of the section for enlargement, the main tunnel was widened from ϕ 12.3m to ϕ 18.3m in outer diameter using Enlargement Shield Tunneling Machine (ESTM), and as a result the launching base for Large Diameter Pipe Roofing (LDPR) was built.
③ A large-diameter pipe (ϕ 1200 mm) was installed from the pipe-roof launching base in the direction of the tunnel axis one by one to form LDPR (27 pipes per block).
④ Chemical grout was injected from inside of each pipe into the ground between the pipes of LDPR to improve the ground to the extent excavation works can be carried out inside LDPR.
⑤ The steel segments of the main tunnel were cut and removed at a width of 4m – 8m in the direction of the tunnel axis, and the ground inside LDPR was excavated.
⑥ After excavation, the concrete structure constituting part of the bifurcation junctions was built.
⑦ The above steps of cutting, excavating, and constructing the bifurcation structure were repeated until the tunnel enlargement was fully completed.

2. Advantages and effects of the technology

① The newly developed Enlargement Shield Tunneling Machine (ESTM) makes it possible to widen the diameter of the main tunnel running under the residential area at great depths, without resorting to the cut and cover method.
② During construction, the tunnel enlargement section was covered by LDPR with extremely high rigidity. LDPR in the excavated sections was supported at all times by the concrete structure and the ground in the still-to-be excavated sections, so stable construction was possible.
③ Possible to minimize the excavation volume in accordance with variations in tunnel cross section profile at the junctions flexibly.
④ No weak point in water-tightness as the tunnel bifurcation had an autonomous elliptical structure on completion without having structural joints between the steel segments and the RC structure.

3. Summary

Through this project, we were able to develop and establish new technologies for the underground tunnel enlargement, proven to be very beneficial for project safety, minimizing the ground settlement resulting from tunnel widening excavation, and reducing impact on the surrounding environment and residential buildings. We could also construct the tunnel bifurcation junctions safely by having protection of pipe roofing that prevented collapse of the ground at the tunnel crown.

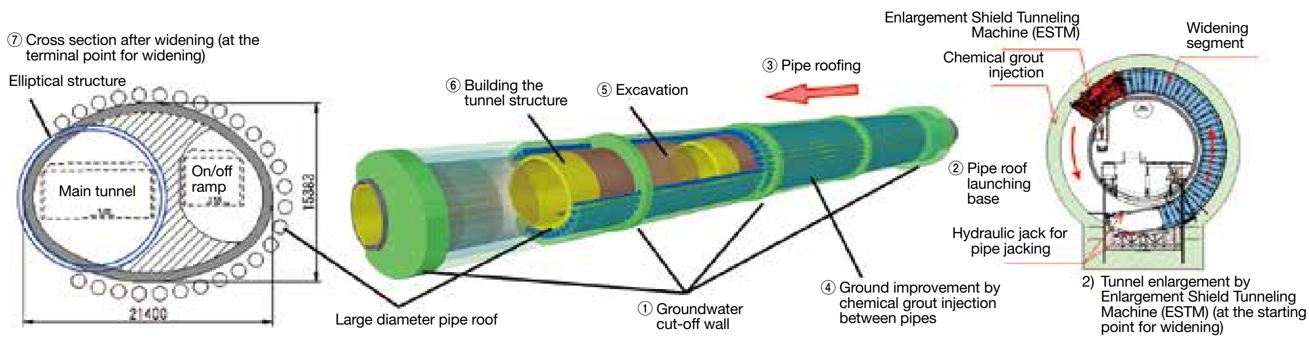

Fig. A new underground large diameter tunnel widening technology that combines Enlargement Shield Tunneling Machine (ESTM) and Large Diameter Pipe Roofing (LDPR)

Construction project on the Namboku Route close to the Port of Tokyo

Seiji TSUJI ▶ General Manager (Engineer), Tokyo Port Office,
Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

1. Summary

The Namboku road on the waterfront of the Tokyo Port is a planned trunk route beneath the sea floor 2.5 kilometers long, linking two areas in the port: the Ariake Area and the Chuo Bohatei Area (central breakwater area) (Fig.1.) In the Chuo Bohatei area of the Tokyo Port, a container terminal is under construction.

It will serve as a link between the above areas, where currently only a single existing route under the sea floor is in operation. It will be named the Tunnel for the Second Shipping Route, which passes along another route. Traffic on this route is extremely congested with delivery vehicles moving around the port area.

The traffic is predicted to grow worse along with development of the Chuo Bohatei Area.

Prior to the Tokyo Olympic/Paralympics Games 2020, 14 athletic fields and stadiums will be built in the waterfront area. During the event, it is feared that the port area will be overcrowded with delivery vehicles and Olympic-related vehicles. Considering these circumstances, we are aiming at opening the route before the Olympic Games 2020 and creating port logistics functions.

This tunnel under the sea floor will be have two lanes in each direction, and the section under the sea floor will be a series of seven immersed caissons respectively 134 meters long, the longest in the country (Fig. 2.)

2. Problems and solutions in the construction of an immersed caisson tunnel

The tunnel spans a distance of 930 meters, linking the Ariake Area and the Chuo Bohatei Area. Generally, any project of the same size will require 8 to 10 years to finish, but this tunnel must be completed within a much shorter time of 4 years.

1) Immersed caisson of fully sandwiched type

In order to streamline the construction process, the structure of the tunnel will be a fully sandwiched type with a steel-concrete composite structure. The steel hulls as caisson will be prefabricated in a dry dock, and then in an assembled state, will be transported to a location on the sea for floating. While floating, the hollow spaces of the caisson walls are filled with concrete (Fig. 3). The advantage of this procedure, in comparison with other types of immersed caissons, is as follows. Caissons are fabricated in the dry dock, thereby shortening the on-site construction period by the amount of time needed for caisson fabrication.

2) Application of the “key element method”

The caisson tunnel will be linked by placing a “key type element caisson” underwater in the final stage between the two tunnel segments coming from opposite directions (Fig. 4). This approach makes it possible to make the construction process shorter and curtail the cost, because underwater work is not required.

3) Use of flexible joints “Crown Seal”

The Crown Seal is used when joining tunnel caissons to allow for deformation in the event of an earthquake (Fig. 5).

This joint is designed to adjust for large deformations by providing a free space between the caisson segments as well as greatly reducing the stress resultant which may occur on the immersed caisson body.

Fig. 1 Location map of Namboku Route

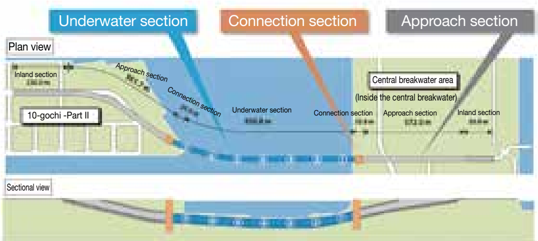

Fig. 2 Plan and sectional view of Namboku Route

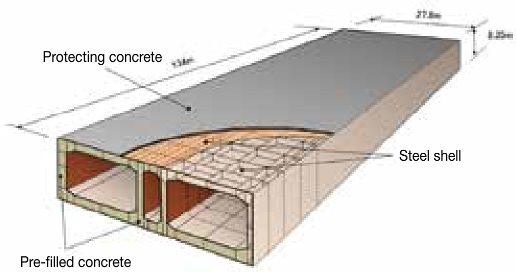

Fig. 3 Steel-concrete composite structure of Full-sandwich type

Fig. 4 Conceptual drawing of the key element method

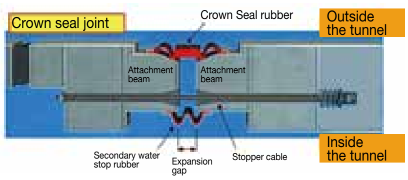

Fig. 5 Crown Seal joint

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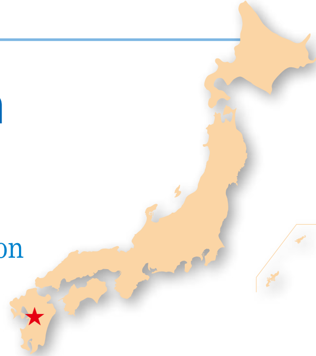

Restoration of a Mountain Tunnel Damaged in the 2016 Kumamoto Earthquake

Shigeru FUKUHARA ▸ Director Engineering Second Division Kumamoto Reconstruction Project Office Kyushu Regional Bureau Ministry of Land, Infrastructure, Transport and Tourism

Kazuhiko NAKAHARA ▸ Construction Manager Civil Engineering Construction Department Kyushu Branch Kajima Corporation

When an earthquake of magnitude 7.3 occurred in April 2016 in Kumamoto (the Kumamoto Earthquake), the Tawarayama Tunnel suffered damage and was undermined along the entire tunnel length and became impassable. This was a tunnel constructed by conventional method where was located about 17 kilometers from the epicenter and within 300 meters of the closest active fault. The tunnel was opened for service in July 2002. This restoration project included inspection of damage over the whole length of the tunnel, designing of countermeasures and restoration of its function.

1. Conditions of the disaster (ground change)

The tunnel was wholly observed and cracks and openings at the joints between the spans of permanent lining were found over the concrete. At several locations, lining concrete had collapsed (Photo 1), and there were cracks and heaving under compressive forces (Photo 2), openings of cracks under shearing force (Photo 3) as well as transversal slippages at the joints, spalling of concrete etc.

2. Selection and implementation of restoration methods

The condition of permanent lining of the tunnel was investigated in detail for damage, and the rehabilitation methods adopted are classified into the following three categories:

1) Removal of the existing lining and replacement of new lining (approx. 160 m)
2) Countermeasure for spalling (injection into cracks, rehabilitation of section walls, carbon fiber sheet attachment, spalling prevention net, application of steel arched support) (about 1,150 m)
3) No countermeasure due to slight or no damage (about 750 m)

For the sections in category 1), after the removal of permanent lining, steel arched support, shotcrete, rockbolt, etc. were visually checked. Buckling deformation was confirmed for a length of about 20 meters (Photo 4). For this section, all existing steel supports, etc., were removed to install new supports (Photo 5). In other sections, steel arched supports were kept as they were, cracked shotcrete was taken away to cast additional shotcrete and rockbolts. For replacement of lining concrete, reinforcement bars were assembled at the site, and then lining concrete, with high fluidity, mixed with plastic fibers was cast.

Of the section of category 1), about 100 meters where the inverted arch concrete had been installed was visually checked for the status of concrete. Along the 60 meter length, at places where there were differences (Photo 6), resulting from destruction of inverted concrete under axial pressure, old inverted arch concretes were removed and new ones were cast. For a stretch of 30 meters with cracks 5 mm or more, non-shrinking mortal was injected.

3. Overview

We started inspection and design in June 2016 while aftershocks continued and traffic was paralyzed, and started construction after this. A maximum manpower exceeding 200 per day was allocated.

Restoring the function of the whole tunnel course in a short period of six months was achieved, with making full use of the technology and management expertise. To meet the needs from the project owner and local residents, the Tawarayama tunnel reopened in December 2016.

Photo 1 Collapse of lining concrete

Photo 2 Compressive destruction and earth heaving

Photo 3 Openings and cracks caused by shearing force

Photo 4 Buckling of steel supports

Photo 5 Reconstruction of a collapsed area

Photo 6 Differences in grade of invert concrete

Construction of a long-distance deep shield that passes through the central part of the Tokyo Chiyoda Trunk Line Project

Mitsuo Mouri ▶ Director, Design Section
Makoto Hata ▶ Deputy Director, Design Section
Tokyo Metropolitan Government, Bureau of Sewerage, 2nd Core Facilities Reconstruction Office

1. Overview of the Chiyoda Trunk Line Construction Project

Many of the existing sewerage trunk lines in the central part of Tokyo have deteriorated considerably, and the water level is consistently high. To deal with this issue, the Bureau of Sewerage of the Tokyo Metropolitan Government is implementing projects for construction of new alternative trunk lines and switching the destination of sewer water in order to reduce water levels in existing sewage trunk lines and reconstruct the sewage system using the rehabilitation method, etc.
A representative example of such projects is the construction of the Chiyoda Trunk Line, a sewage line that starts at Iidabashi (the uppermost region), passes through the central part of Tokyo where numerous government ministries and agencies are located, collects sewage water from six existing sewage trunk lines, and ends at a sewage water treatment facility. A large-face shield with an external diameter of 5.5 m (internal diameter of 4.9 m) was necessary in order to build the sewage main line. With its total length of 8.7 km and maximum overburden of approximately 60 m, this shield tunnel construction project is without precedent in terms of depth and scale of construction work. Furthermore, in order to improve the quality of water in Tokyo rivers, the Chiyoda Trunk Line construction project will also serve to improve the combined sewerage within the drainage area by significantly reducing the spillage of sewage water in public waters during rainy weather.

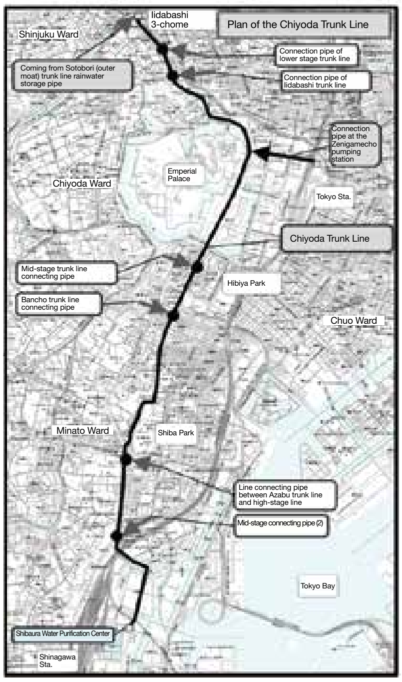

Fig. 1 Plan

In addition, a multistage bit arrangement with protruding advance cutters was adopted as a measure to handle long-distance excavation in hard ground with an N value ranging from 100 to 150. In this arrangement, extra-hard bits were used in the reinforced advance cutters in order to eliminate the necessity of bit replacement. Furthermore, an emergency water shutdown device was installed to deal with deterioration of the tail brushes, and specifications were adopted to enable replacement of tail brushes in emergency situations.
Construction and connection of manholes for water intake, was designed presuming adoption of the Urban Ring Method, which can be utilized at significant depths, and the freezing method, which is commonly used with good results by the Bureau of Sewerage in the Tokyo Metropolitan Government.

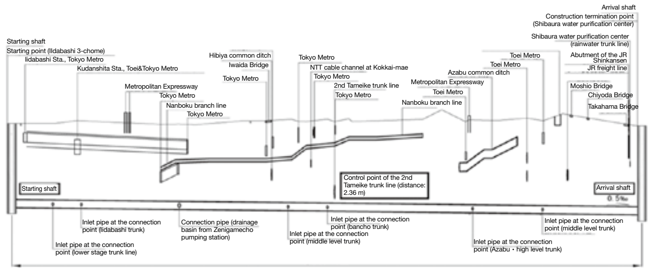

Fig. 2 Longitudinal section

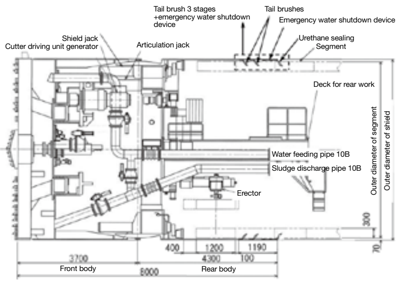

Fig. 3 Shield machine (standard plan)

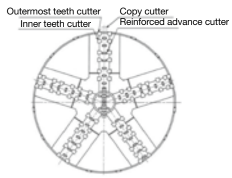

Fig. 4 Shield machine (face plate)

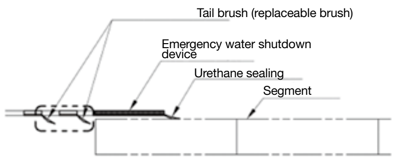

Fig. 5 Overview of the tail brush replacement

2. Overview of design

The starting shaft was located in close proximity to a railway line in service, so the Pneumatic Caisson Method was adopted because it has little effect on the surrounding environment. Also, the construction yard was quite narrow because of its location in the central part of Tokyo, so part of the road was utilized and construction was carried out underneath the road.
The mud water compression shielding technique, which features degree tight seal to the ground and enables automated control of the intake of soil, was adopted in order to deal with the envisioned high water pressure of 0.5-0.6 MPa in the tunnel. In order to be able to control the water effluence caused by the increase in pressure during excavation, a shaft entrance capable of handling high pressure was adopted.

3. Conclusion

The progress of the Chiyoda Trunk Line Construction Project is as follows. Construction of the starting shaft was launched in March 2014 and completed in December 2016, shield operations started in November 2016, and shield machines and segments are currently under construction.
Sewerage construction work is conducted almost entirely underground, and the public lacks sufficient awareness of such projects. To deal with this issue, details of the Chiyoda Trunk Line Construction Project are published on the website of the Tokyo Metropolitan Government Bureau of Sewerage as an example of a large-scale construction project, in order to disseminate information in a manner that is comprehensible to the general public.

Direct excavation of RC structures with a shield machine and construction of a sharply curved alignment

Atsushi TANAKA ▶ Chief, Underground Regulating Reservoir Beneath Ring Road No.7 Construction Office, TAISEI CORPORATION

Introduction

The Tokyo Metropolitan Government is planning to construct an underground wide-area, tunnel type reservoir for flood control, along Ring Road No. 7 to temporarily hold floodwaters during typhoons and localized rainstorms.

This construction section is 5.4 kilometers in total linking the two regulating reservoirs in service, Kanda River-Ring Road No. 7 underground reservoir and Shirako River underground reservoir. The tunnel is 13.2 meters in outer diameter and 12.5 meters in inner diameter, which will be built using a slurry shield method, along a trunk road at depths of 32 meters to 40 meters.

The shield machine is currently being manufactured and will be launched for the project in July 2019.

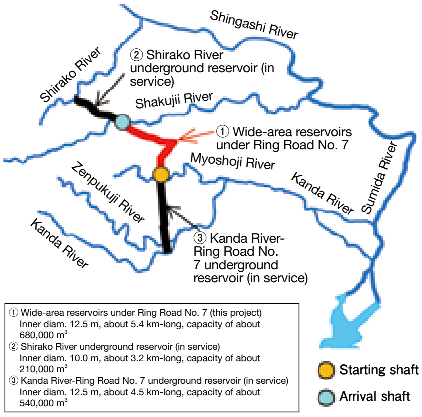

Fig. 1 Overview of the wide-area reservoirs

(1) Cutting RC structures underground on site directly with a shield machine

The shield machine, after being set in the starting shaft, will directly commence cutting the lateral walls (RC structure, thickness 1.7 m) of the starting shaft, and RC wall diaphragms (1.2 m thick). When the shield machine directly cuts materials in the starting shaft, the structural materials encountered are normally not steel, but carbon fibers and FFU components (Fiber Reinforced Foamed Urethane) because they can be cut with ease. But this project does not use such materials. In the past, there were cases where RC structures such as embedded ducts and piles were cut directly, but cutting RC structures directly in a full-face excavation as seen in this project has no precedent.

The cutter head is a conical shape which, on the entire surface, is provided with carbide bits suitable for a full-face excavation that are ultra hard, approximately 48 times harder than conventional preceding bits used generally for soil and sand stratum. After the process of direct cutting, the shield machine, thanks to the use of bits with greater endurance that are highly resistant to wear and impact, will be able to excavate a tunnel length of 5.4 km without changing the bits.

When cutting the existing structures underground, the rotation speed of the cutter will be approximately doubled (to 0.84 rpm) and the shield machine with continue boring at a low rate of 1-2 mm/min in a manner to thinly peel the structure surface off.

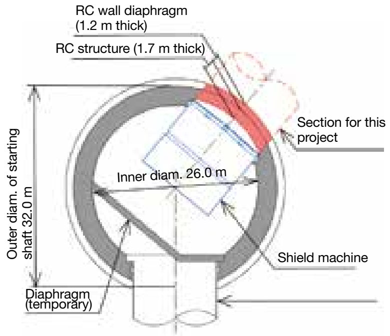

Fig. 2 Starting shaft for the shield machine

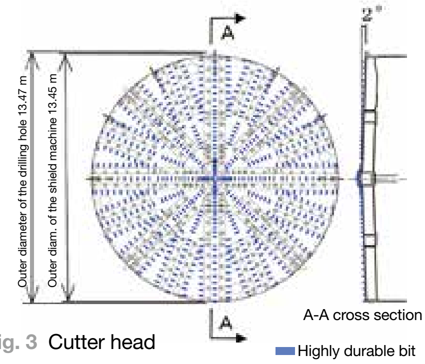

Fig. 3 Cutter head

(2) Boring a sharp curve

The minimum curve radius is 100 m in horizontal alignment for the tunnel. Given 13.45 m as an outer diameter of the shield machine, R=100 m is one of the sharpest curves attempted for large section tunnels. To keep the horizontal alignment optimal, the articulation angle of the shield machine is set to 4.3 degrees max. The segment portion at a sharp curve excavation is composed of rings tapered to form the shape of a curved cornice along its total length (Fig. 4).

Since generally, the section at a sharp curve tends to be over-broken, highly cohesive plastic filler will be injected into the ground from the side barrel of the shield machine to prevent the porous ground from collapsing, and by doing so, will minimize excavation impact on the ground surface.

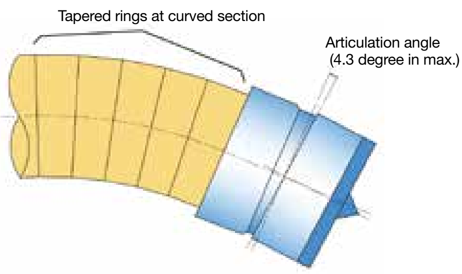

Fig. 4 Construction of a sharply curved section

Construction of a shaft and a water-tight pressure tunnel with a large cross-section in a lake

- Project for construction of a new spillway at the Kano River Dam Tunnel

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Shinya UEOKA ▶ Manager, Civil Engineering Department, Kansai Regional Branch, Shimizu Corporation
Ryoichi YOSHIOKA ▶ Manager, Civil Engineering Department, Hiroshima Regional Branch, Shimizu Corporation
Hiroshi MOTOMURA ▶ Manager of Civil Engineering Planning Department, Kyushu Regional Branch, Shimizu Corporation

This project is concerned with the construction of a tunnel spillway 11.5 m in inner diameter in the ground on the right side of an operating dam. The structural elements to be provided from upstream were an influent channel, an intake shaft, a tunnel, an outfall and an energy dissipator (Photo 1.)

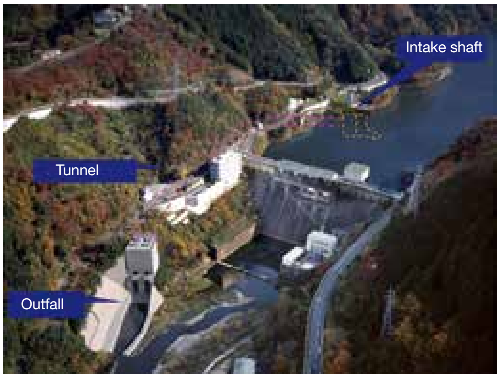


Photo 1 Construction map

1. Pressure tunnel with a large cross section

This tunnel is a pressure tunnel in which water pressure is extremely high, with external water pressure up to 0.9 MPa and an internal water pressure up to 0.4MPa. Of a total length of 457 meters, 323 meters were constructed with standard structures of reinforced concrete, and the remainder composed of steel pipes such as effluent pipes, transition pipes. The boring cross-section of the tunnel was 142 m^2 for standard structure, and 322 m^2 (width 19.1 x max. height 19.2) for a steel pipe section, which boasts the world's largest size as a pressure tunnel. The section of reinforced concrete did not depend on water sealing grouting for water tightness, which is normally used for pressure tunnels, but on a system of applying water-tight sheets to the total circumference. In order to lower the risk of water leakage, we contrived a new approach for finishing the wall surface. The tunnel walls were made smooth with shotcreting prior to application of water-tight sheets to reduce the number of times sheets had to be welding by changing the sheet width from 2 meters to 3 meters.

As reinforcement material, we introduced prefabricated mesh reinforcement in units, which are designed for lower risk of damage and for saving labor (Photo 2.)
The lining concrete that was used was the type with medium fluidity which is able to completely fill the cavity.

2. Excavation of a shaft at great depths

The intake shaft was built in the lake, in the shape of a cylinder by driving 34 steel pipe sheet piles of 1500 mm in diameter (L=44.0 m), which was temporarily water-proofed. Inside of the shaft, excavation was made from the top of sheet piles to a depth of 41 m by installing ring-shaped supports (H-300 in two stages, H-400 in four stages and H-800 in four stages.) Then, concrete was placed underneath to build the bottom slab before being temporality back-filled. After cutting the steel pile sheets, the shaft was linked through penetration with the tunnel which had been bored from the outfall side. During the excavation of the shaft, there was a risk that the steel sheet piles might deform to create bleeding channels, leading to significant groundwater inflow. Measurement instruments were placed on the steel pipe sheet piles and supports for around-the-clock monitoring.
(3) Excavation for the penetration of an intake
The excavation for the penetration of the intake has the following features: 1) 14 of the steel pipe sheet piles at the intake shaft were cut; 2) The outer circumference of the steel pipe sheet piles, after being back-filled with single-sized crushed stone, was water-proofed by injecting underwater inseparable cement milk; 3) The tunnel to which the intake was to be connected had a large cross-section with a boring surface of about 270 m^2 (17 m wide x 17.9 m high.) Prior to cutting of steel pipe sheet piles, a hole was bored for monitoring to confirm there was no water inflow from behind steel pipe sheet piles. The face was divided into four benches, by cutting steel pipes with a grind-stone cutter and Sharp Lance. During the whole process to the moment of breakthrough, the project was completed safely, with neither abnormal deformations in the shaft and tunnel, nor inflows from the connected sections (Photo 3.)

Photo 2 Completion of the reinforcement

Photo 3 Full view of the connection in the outfall

Widening of an extremely large underground cavity from small aqueducts

Keisuke HIGO ▶ Deputy Director, Kyusyu Branch, OBAYASHI CORPORATION

This is a new project for construction of a 659-m long irrigation and discharge tunnel with the main objective of maintaining the flow discharge from the Koishiwaragawa Dam (under construction by the Japan Water Agency in Fukuoka Prefecture) and reaching the amount of discharge necessary for supply of water for the waterworks system. One of the characteristics of the construction is the specific location of the discharge equipment chamber, which has an extremely large cross-section (250 m^2), where valves are installed to control the discharge volume. The zone is sandwiched between zones with smaller cross-sections (29 m^2) of the upstream aqueduct and the downstream aqueduct.

1. Overview of the geological conditions

The geology of the tunnel is composed of hornfels from psammitic schist of the Sangun metamorphic belt dating back to the end of the Paleozoic Era through the early Mesozoic Era. It is relatively hard with uniaxial compressive strength of about 80 N/mm^2. The lithology of the discharge equipment chamber features sound rocks overall, but there is intercalation of clay in the joint faces.

i)Issues pertaining to the excavation method and solutions

Issues

- Initially, the plan envisioned a tunnel constructed as a three-turn slanted structure extending upwards from the downstream side. The excavation of the crown section raised concerns of collapse of natural ground due to the proximity of construction to the already completed upper section of the drift and delays of the construction process due to the complexity of the excavation.
- Since the discharge equipment chamber was a zone with extremely large cross-section sandwiched between zones with smaller cross-sections, the environment aggravated retention of dust.
- In the excavation equipment for the small sections, the equipment arm could not reach the excavation location, so it was impossible to excavate the full face of the arch section without replacing the equipment.

ii)Solutions

- Excavation was launched from the upstream side with due consideration of the 5% longitudinal slope. The number of turns was changed from three to one, and the slope of the drift was planned at 23% of the grade ability of the equipment.
- As a solution to the issue of retention of dust inside the extra-large sections, a ventilating hole was installed to connect the upstream portion with the downstream. Also, a silent fan was used to supplement the effect of the ventilating hole, and the necessary ventilation volume was maintained at over 937 m^3/min.
- The cross section of the tunnel heading was built by dividing it into right and left half sections. In order to maintain the stability of the supports in the half sections, the steel supports were fixed by installing temporary anchors (D25, L=2.0 m) (two anchors per support).

Figure 2 shows the steps in the excavation process.

2. Summary

The reduction of the number of turns of the tunnel structure during excavation served to simplify the construction methods, and resulted in improved safety and shorter construction period. Also, the utilization of the ventilating hole for water supply and drainage as well as electricity supply during the excavation for the turn structure not only improved the work environment but also boosted operational efficiency.

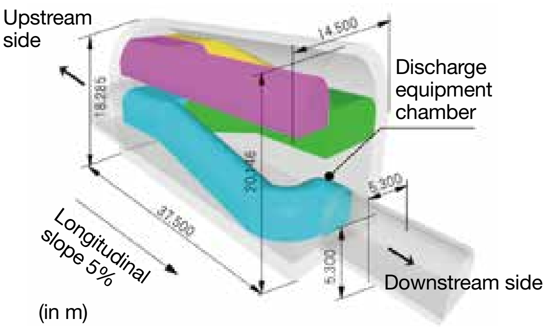


Fig. 1 Initial excavation plan diagram

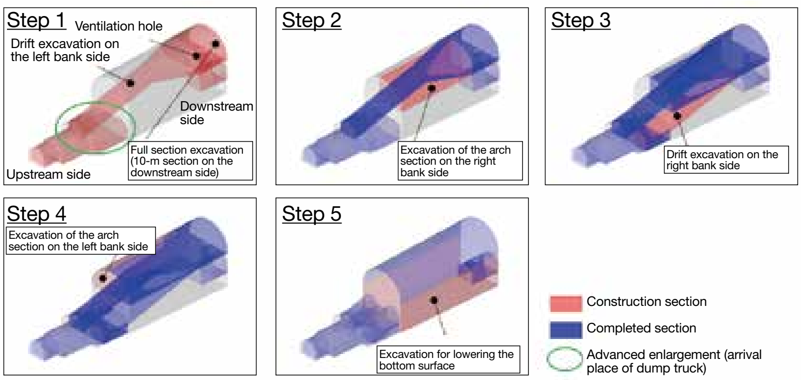


Fig. 2 Steps in the excavation proces

Construction of an Underground Power Plant by Remodeling an Existing Plant

— Project for remodeling the Bunsui Power Plant No.1 at Shikoku Electric Power Co., Inc.

Takashi KAJI ▶ Manager, Hydropower Dept.System Operation & Transmission Division

In recent years, the weather pattern has dramatically changed, and there are frequent torrential downpours. Because of these conditions, this project was aimed at demolishing a hydropower plant on the ground whose equipment was at a risk of deterioration and damage in the event of a landslide. To avert this danger, a new underground hydropower plant was planned for the relocation of the old one. The project started in April 2013, and the new plant was completed in April 2017, ready to start operation. In September of the same year, all related work including removal of the old power plant was completed.

1. Layout

The underground hydropower plant was located at a considerable distance from the landslide block, more than twice the height of the cavity for the plant to be free from impact by excavation of the underground cavity or a landslide. For a new plant layout, making the best use of the existing water intake and penstock, a new penstock was provided, along approximately the 190 meters to connect the existing penstock and the new underground hydropower plant, as well as a new diversion channel about 200 m long between the underground power plant and the existing discharge port, respectively in the shortest distance.

2. Design of the underground cavity

The underground plant was constructed under a slope producing localized pressure, and the geology to be excavated was composed of pelitic schist (black schist) with a strong anisotropy, involving developments of schistosity. The behavior at the time of excavation was considered to be dominated by anisotrophy and fissility; for such geology, the use of conventional isotropic model was considered to be difficult to simulate the rock behavior accurately. By deeming the formation of schistosity as a discontinuous surface, we used a multiple yield model (MYM) belonging to the equivalent continuum analysis method for the analysis of cavity excavation. Based upon analysis results, the supports of the cavity were designed.

3. Blasting excavation in the vicinity of an existing power plant in operation

The cavity and penstocks for the underground power plant were planned to be excavated in the vicinity of an in-service power plant and landslide block, so we were required to excavate without any impact on such facilities, while the power plant was kept in operation.

To cope with the problem, actual measurements of the landslide were used to verify a relationship between blasting vibrations and landslide volumes to derive a new vibration management level based on our study. Blasting was done methodically adjusting the amount of explosives and their configuration, while measuring vibrations. As a result, the existing plant has been kept in operation during a blasting excavation period of as long as 17 months. Power generation was suspended only three months out of the 54 months required for connection between new and old penstocks.

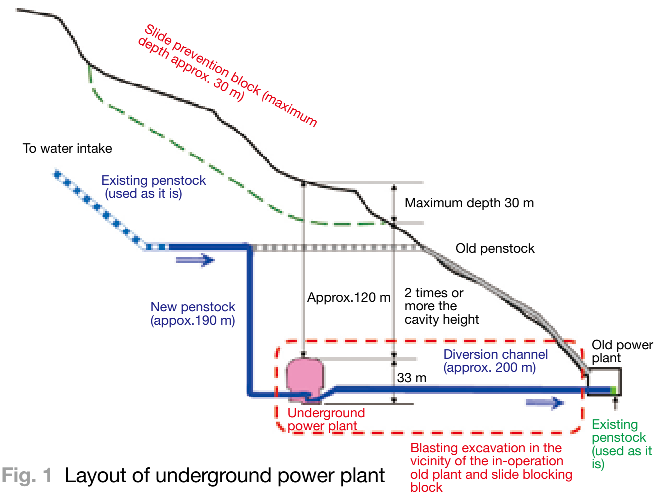


Fig. 1 Layout of underground power plant

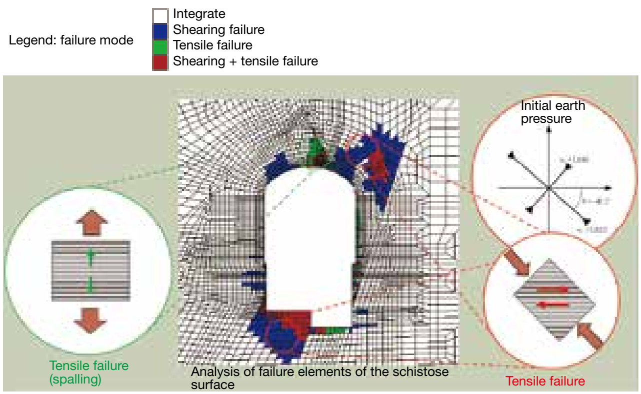
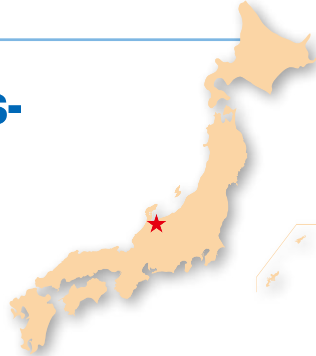


Fig. 2 Results of cavity excavation analysis by MYM

Location of the underground plant View of plant interior

Fig. 3 Location of the underground plant and view of interior



Construction of a gas pipeline using small cross-section shield tunneling for rocks under high water pressure

Kaoru TOYA ▶ Tamagawa Hydro-Electric Power Plant(HEPP) No.2 Construction Site, Office Project Manager, OBAYASHI CORPORATION

The Toyama line, a 102 km-long natural gas pipeline, was constructed from Itoigawa City, Niigata Prefecture to Toyama City, Toyama Prefecture for the purpose of expanded use and stable supply of natural gas. This project laid a gas pipeline under high pressure in Construction Segment A-1 which is nearest to the starting point (on Niigata side). A tunneling segment of about 2 kilometers out of the total length was designed to pass through the mountain area, considering that severe traffic congestion could potentially be caused by large vehicles used for muck hauling as well dust, noise and vibration that would occur during excavation.

Ground condition and construction plan

This tunneling segment is mainly composed of collapsing and crushable brecciated slate and Holocene sandy soil with an earth covering of 10.5 to 117.5 meters, with an assumed maximum groundwater pressure of 1.2 MPa. When establishing this tunnel plan, the crucial requirement was that the construction process should be managed so as to put the Toyama line in operation as soon as possible, and to achieve this goal, two tunnels were excavated from opposite directions at the same time, and docked with each other at the mid-point for breakthrough.

Of the tunneling course, the segment beginning from the starting portal up to about 200 meters included highly permeable sandy ground. Considering that a NATM method, if employed, may be less efficient and economical because it is necessary to use various auxiliary methods such as water sealing injection and long forepiling, we adopted a muddy soil pressure balanced shield method, which proved to be effective for both rock ground and sandy soil (850 m long, shield outer diameter 2280 mm, segment's outer diameter 2150 mm).

Pressurized excavation in the sandy section and open excavation of the rock section

The 200 m section from the point where the shield machine started excavation, being composed mainly of gravel-mixed sand, was bored under pressure with the use of bentonite muddy water and air bubbles, but during the excavation, observing that the soil became gravel-like, and the screw was frequently clogged with gravel 40 mm in diameter, it was feared that the excavation might be impossible.

Therefore, we judged that the status in the chamber could not be stabilized, and decided that the chamber should not be filled with muck, but that the face should be excavated with an open-type shield method. At places where water flow was estimated to be relatively small, drainage was omitted. By doing so, excavation proceeded by discharging water inflow with additives from the screw conveyor. At places with large amounts of water inflow, the excavation was controlled by draining water from the shield and segments so it did not exceed the pressure resistance of the shield machine. At a drainage level of 2000 L/min at the final stage, excavation was able to be completed successfully by preventing the clogging of the screw and chamber. The longitudinal alignment of the tunnel was designed at 0.3% in advance; the water inflow in the tunnel was made to flow naturally under gravity.

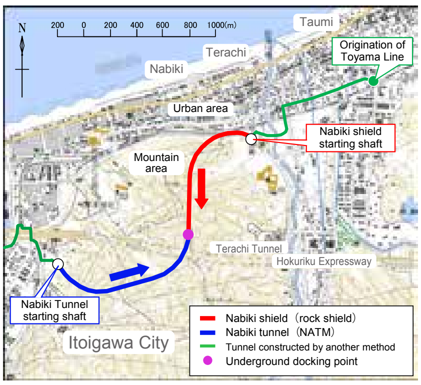


Fig. 1 Tunnel plan view

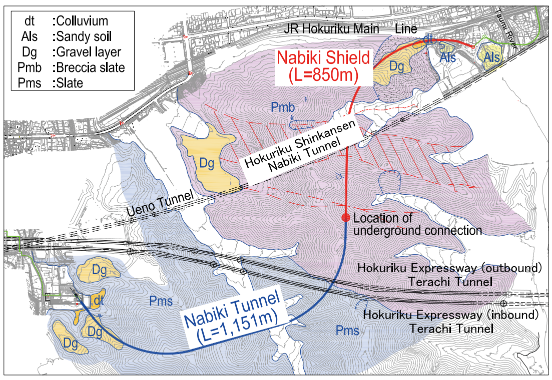


Fig. 2 Plan view of geology and tunnel alignment

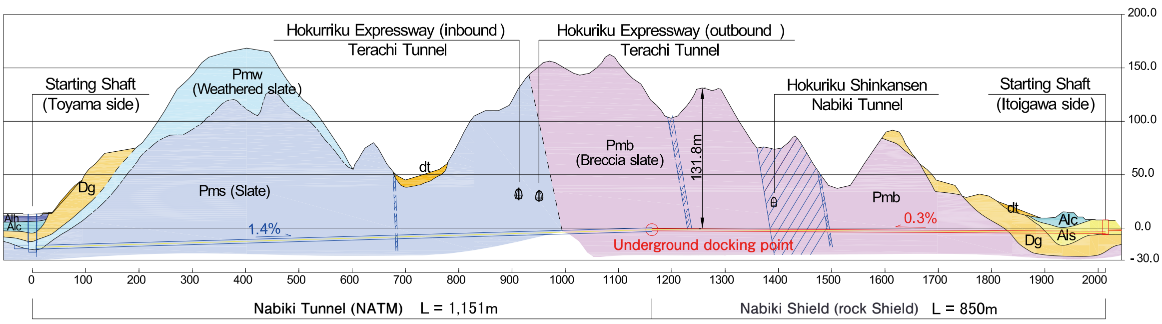


Fig. 3 Tunnel longitudinal profile

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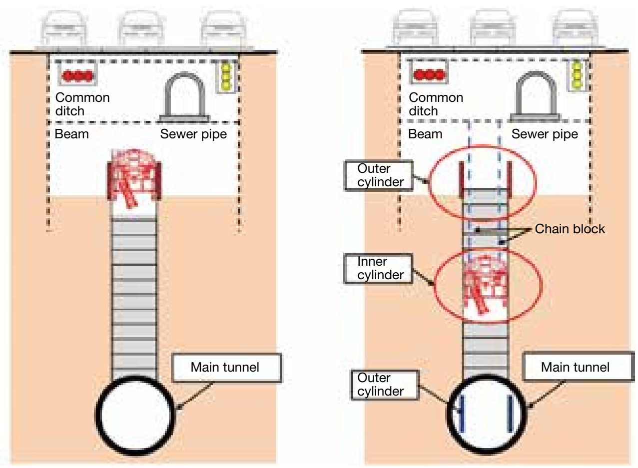
Development of an Upward Shield Machine Retrievable Through a Tube

Yuta KAWAGUCHI ► Construction chief
Kansai Branch Office, TAISEI CORPORATION

As part of flood prevention project by the city of Osaka, a rainwater reservoir pipeline system with a capacity of 90,000 tons of rainwater is to be constructed for the segment from Shin-Imazato to Teradacho, consisting of a rainwater reserve tunnel and specially designed manhole shafts in a few places. The particular manhole shaft this paper reports about was located in the road in the Osaka Loop Line with 6 lanes (3 lanes in each direction), and there were many residential houses and public facilities such as hospitals in the vicinity, which made it difficult to bore the manhole shaft from the surface.
To accommodate these construction conditions, a special shield machine called "upward boring shield machine of type retrievable into the main tunnel" was developed and deployed at the site. In this process, the shield machine was positioned at a predetermined location in the tunnel to start boring upward up to the ground surface to build a manhole shaft, and then was lowered into the tunnel for recovery. This shield machine consists of an inner cylinder integrating a cutter on the head and a cutter-driving unit inside, and an outer cylinder. After arriving at the top of the connection shaft (as shown in Fig.1-(1)), the inner and outer cylinders which are connected by means of pins are separated from each other. First, the inner cylinder is lowered to the bottom of the tunnel for recover, and then, the outer cylinder in the same step for reuse (as shown Fig. 1-(2), Photo 1).

The boring method has the following features
- The shaft can be built without being affected by embedded obstacles, and disassembling of the shield machine and lowering while suspended are possible even in a narrow space at a site with underground obstacles.
- The outer cylinder can be optionally changed in diameter to fit its size to the bore size.



(1) Boring and arrival just under the embedded object

(2) The outer and inner cylinders are separated from each other to be recovered in the main tunnel.

Fig. 1 Conceptual diagram of the upward shield machine removable through a tube

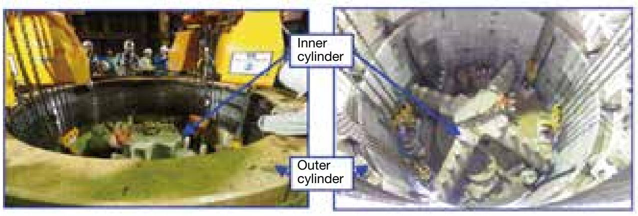


Photo 1 Construction using the upward shield machine

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Hard Rock Tunnel Boring Machine TM-100

Applied to the boring of hard rock with a uniaxial compressive strength 100 MPa

Masanori WAKAYAMA ► Machinery Department Manager, Civil Engineering Division, TAISEI CORPORATION

Minimizing the environmental impact is one of the essential requirements in tunnel boring in order to preserve the natural environment, buildings, and embedded structures at the site. In addition, it is important to save the environment of neighborhood residents. From these background, the use of impact-producing excavation depending on explosives and large-scaled breakers are restricted for many sites. In order to cope with this issue, a new type of tunnel boring machine TM-100 (hereinafter referred to as TM-100) was developed to bore hard rock.

1. Characteristics of TM-100

- A disk cutter is provided on the machine, capable of crushing hard rock exceeding 100 MPa for any free cross section.
- There is also a disk cutter able to crush material with low vibration.
- Automatic boring is possible to improve boring accuracy and quality.
- To save worker's safety, it is able to eliminate for workers to enter the area just in front of the face
- An automatic operation saves labor forces.
- Since an assembling time of the machine at site can be decreased to only a week, a site schedule can be optimize anytime when required.

2. Application to a tunneling site

In 2015, TM-100 was installed for a tunnel construction on the Shin-Meishin Expressway. This site is located in the proximity of a residential area, national highway and railway, including some sections where explosive boring was prohibited, and partially encountering hard rock exceeding 100 MPa in uniaxial compressive strength. Since it was predicted that excavation would be difficult with a conventional tunnel boring machine, we decided on using TM-100. Although some sections in the alignment to be bored included hard rock layers of 200 MPa, the project was able to be completed safely. The result of vibration measurements in the vicinity were less than 50 dB, the upper limit permitted by regulations, and capability of a monthly rate of 35 meters was demonstrated.

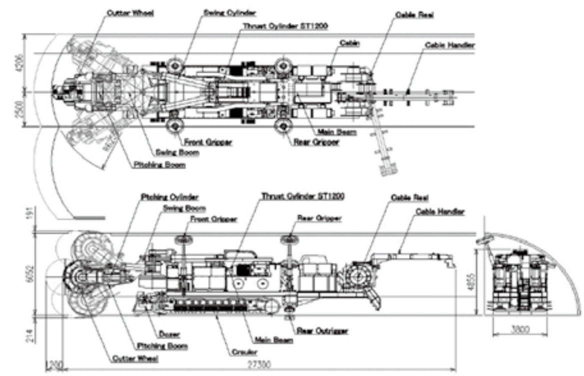

Fig. 1 Plan and sectional view

Photo 1 Boring machine

Photo 2 Excavation

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FSC-100, machine drilling of an extremely long pilot hole

Hiroshi OSHIMA ► Supreme Technical Advisor, Kokusai Kougyo Co., Ltd.
Hiroyuki HAGIHARA ► Technical Manager, Social Infrastructure Dep., Kokusai Kougyo Co., Ltd.
Satoshi IKIMORI ► Deputy General Manager, Engineering Div., Koken Boring Machine Co., Ltd.
Kazuma SUZUKI ► Manager, Chuo Shinkansen Promotion Division, Central Japan Railway Company

1. Summary of the technology

FSC-100 is a boring machine that can rapidly drill extremely long exploratory holes of 1000 m or longer without coring, controlling the drilling direction ahead of the face. This technique enables us to acquire geotechnical conditions in the tunnel and groundwater conditions required for long-term planning of the construction. Also, the construction feasibility can be assessed adequately. Furthermore, large amounts of pressurized groundwater can be extracted beforehand which makes construction easier.

Features of FSC-100
① Able to drill holes of 20 to 30 cm in diameter, at a maximum speed of 100 m per day, even under circumstances where a large amount of pressurized water inflow occurs.
② Drilling direction can be controlled (within ± 5 m per 1000 m)
③ Compact design advantageous for installation in the tunnel.
④ Data acquired during drilling can be converted into geotechnical information beneficial for tunneling.
FSC-100 system consists of a drilling machine, downhole motor, drilling direction measurement unit, drilling tools and high pressure pump to drive the downhole motor as shown in Figs. 1 and 2.

2. Achievements so far with FSC-100

This system has been employed for more than 10 construction projects of long hole drilling. We have improved the machine and enhanced engineering skills for the overall technique of drilling and data analysis.
Main results and data are summarized below:
- Maximum excavation length: 1200 m, average: about 700 m
- Average drilling speed is from 18 to 37 m/day.
- Tunnel alignment can be controlled within 5 m in the target direction.

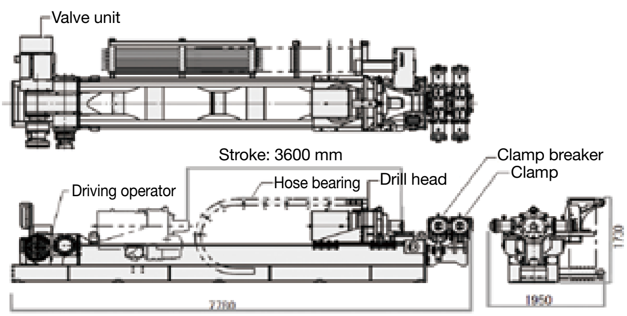

Fig.1 Schematic views of FSC-100

Fig.2 Construction with the FSC-100

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Technology for measurement of potential water inflow collected ahead of the tunnel face

Yoshinori KITAMURA
► Senior Engineer, Civil Engineering Design Division, Kajima Corporation

1. Overview

Gathering of advance information on the situation of potential water inflow ahead of the tunnel face is extremely important in order to maintain construction safety. In long tunnels, in particular, it is difficult to conduct multiple surveys from the ground surface, so it is necessary to acquire information regarding the geology and potential water inflow ahead of the tunnel face by the horizontal boring. As a solution for this difficulty, we developed a system that enables accurate and continued automated measurement of spring water pressure and volume ahead of the tunnel face simultaneously with FSC-100. Evaluation of the information regarding water inflow obtained through this system in combination with the geological information obtained through FSC-100 enables assessment of the ground conditions ahead of the tunnel face and is useful in determining the necessity of countermeasures for water inflow.

2. Characteristics

Conventional surveying and measurement of spring water are conducted intermittently at the opening of the drilling shaft, but with this method it is difficult to obtain accurate information about spring water where there are multiple spring water zones. By applying the two technologies summarized below, the newly-developed system enables measurement of spring water pressure and volume long hole drilling.
(1) Measurement of spring water pressure at the tip
A self-powered water pressure measuring unit installed at the tip of the drilling machine makes it possible to measure the spring water pressure around the tip of the drilling hole. This enables gathering of precise information about the location and size of each spring water zones.
(2) Automated measurement of spring water volume at the mouth of the drilling hole
In long hole drilling, the volume of spring water is estimated by monitoring the drainage discharge at the mouth of the drilling hole. As an alternative solution to intermittent manual measurements, an electromagnetic flow meter is provided at the mouth, and in this arrangement, it becomes possible to measure possible water inflow automatically and continuously without human intervention.

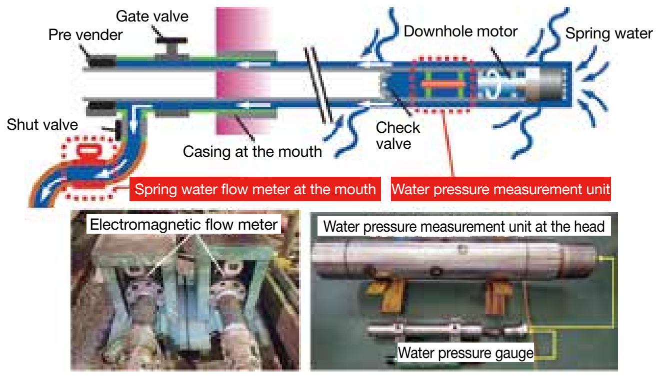

Fig. 1 Structure of the system for measurement of spring water pressure and volume

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High-compactability concrete: Concrete that enables economic construction of high-quality lining

Atsumi ISOGAI ▶ Deputy Director, 2nd Design Division, Design Department, Japan Railway Construction, Transport and Technology Agency

Kuniaki SAKURAI ▶ Chief Researcher, Construction System and Materials Department, Technical Research Institute Technology Division, OBAYASHI CORPORATION

Construction of tunnel lining requires placing and compaction of concrete in an enclosed space, and involves risks of material separation and filling defects.

High-compactability concrete is a type of concrete that has the same unit water content and cement content as conventional concrete (15cm slump), but boasts superior fluidity, material segregation resistance, and filling capacity (Photo 1). Figure 1 is a conceptual diagram of the ratio of ingredients.

High compactability concrete has the following characteristics.

(1) The water content and cement content are the same as those in conventional concrete, so there is no increase in material costs and it is possible to prevent the occurrence of shrinkage cracks after hardening.

(2) Coarse aggregate with a maximum size of 40 mm is used, so the lateral pressure on the tunnel lining form is equivalent to the lateral pressure when conventional concrete is used, and there is no need for reinforcement of facilities.

(3) The concrete has high fluidity (21 cm slump) and filling capacity (over 28 cm filling height), so it easily flows and fills up the form to full capacity through light compaction even in crown sections.

(4) By using fly ash (powdery substance, powder-based high compactability concrete) and water reducing admixture (thickener, thickener-based high compactability concrete) that contains thickening ingredients, it is possible to prevent occurrence of back side cavities and clogging during pressure-feeding caused by material segregation.

Currently, high compactability concrete has been applied to tunnel lining construction on the Hokuriku Shinkansen Line.

Photo 1 External view of high compactability concrete

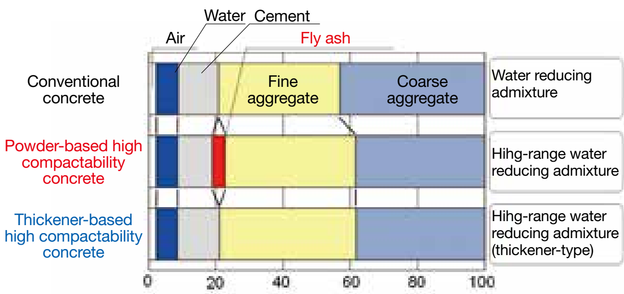

Fig. 1 Conceptual diagram of the ratio of ingredients of various types of concrete

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Reduction of water inflow into tunnels, using ultrafine cement

Hitoshi TEZUKA ▶ Kumagai Gumi Co., Ltd.

Kumagai Gumi Co., Ltd. has developed an innovative inflow blocking system for tunneling. Featuring a post-grouting method, the blocking system forms a ring of improved water-tight ground 3 meters thick on the whole sectional circumference, from inside the tunnel (Fig. 1).

Conventionally, slag cement (10 μm in average diameter) and superfine particle cement (4 μm in average diameter) have been used. Since it is difficult achieving a target permeability of 4 x 10^{-6} cm/sec in ground with these materials, we determined to use new ultrafine particle cement (1.5 μm in average diameter) which is excellent in permeability.

During boring the Hokusatsu Tunnel, a huge water inflow containing a high level of arsenic occurred.

In particular, a 100-meter section, extending from 1,800 meters to 1,900 meters from the portal, was situated in a zone with low boring rate where there were many cracks in the boundary of the granite and a layer of alternating sandstone/shale . This section also was highly prone to water inrush of approximately 300 tons/hour, with a total arsenic amount of 0.16 mg/L (Photo 1).

For the project, we were required to provide a permanent measure for blocking arsenic water inflow.

Thanks to the blocking measure which was provided for the section of 100 meters, the water inflow was reduced from a maximum of 300 tons per hour to less than 40 tons per hour.

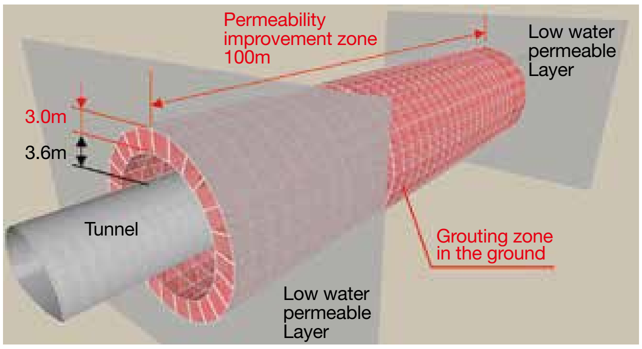

Fig. 1 Diagram of ground improvement zone

Photo 1 Water gush during tunnel excavation

Rock Grouting Technology for Reducing Groundwater Inflow in Deep Underground

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Koki IKEDA ► General Manager, Geoscience Facility Construction Section, Tono Geoscience Center, Japan Atomic Energy Agency;
Shin-ichiro MIKAKE ► Manager, Geoscience Facility Construction Section, Tono Geoscience Center, Japan Atomic Energy Agency;
Hiroya MATSUI ► Principal Engineer, Crystalline Environment Research Group, Tono Geoscience Center, Japan Atomic Energy Agency.

1. Mizunami Underground Research Laboratory

JAEA is operating the Mizunami Underground Research Laboratory (MIU) project in order to establish a firm scientific basis for safe geological disposal of high-level radioactive waste. The geology below 170m depth consists of Cretaceous granite. It has been essential to develop rock grouting technology in the conductive zones as a countermeasure to minimize water inflow into a tunnel in the view of grological disposal in JAPAN. We have applied various materials such as ordinary cement, superfine cement, and a liquid type durable grout, colloidal silica grout (CSG) to seal fine rock fractures. The CSG is composed of activated silica colloid with gelling property and its penetrability is much higher than that of cement due to a particle size of a nanometer.

2. Grouting experiences in 500m depth

We have recently conducted pre- and post-grouting works at a gallery in 500m depth of MIU. The groundwater pressure was around 3.5–4.0MPa and a maximum grouting pressure was set to 5.5MPa. As a result, water inflow was reduced to a one-hundredth of an assumed amount with no grouting were performed, which is reduction from approx. 6,000L/min/100m to 60L/min/100m. Moreover, after a later post-grouting work repeated in the most wet section of the relevant gallery, all dripping spots turned out to be lower than 1 L/min, which is assumed to be a criteria for post-grouting of point leakage in disposal tunnels in Sweden.
Especially for the post-grouting technologies, three new concepts were demonstrated and found to be effective; which is the CSG for a new material, complex dynamic grouting method (Fig.1) for a new injection method, and sealing outer area of pre-grouted zones (Fig.2) for a new grouting area as design concepts.

3. Conclusion

It can be concluded that this technology is applicable to general tunnels in hard rock with abundant fractures and a severe inflow requirement, and to construct the future disposal tunnels in deep underground, accordingly decreasing maintenance costs such as longtime water discharge in disposal projects.

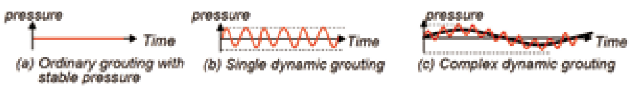

Fig.1 Concepts of different injection systems regarding grouting pressure with time.

Fig.2 A schematic view of the new design in post-grouting zone, which is outside of the pre-grouted zone in the right compared with a view of the traditional design in the left.

New energy-saving cutter structure for large section shield machines for rapid construction

Hiroshi UEDA ► Manager
Civil Engineering Technology Division OBAYASHI CORPORATION

Background

Operation of shield machines requires enormous amounts of electrical power, and 70% of this power is used to drive the cutter, which excavates the ground. An energy saving shield construction method that uses a double-cutter mechanism was developed in order to reduce the power consumption of the cutter shield construction method.

Summary

Unlike the conventional single-drive mechanisms, in the double-cutter mechanism, the cutter head of the shield machine is divided into an inner circumferential part and an outer circumferential part, which can be operated independently of each other. This structure allows the optimal rpm for the inner circumferential part and the outer circumferential part to be selected separately (Fig. 1). With this design, it is possible to control the rpm of the outer cutter which is normally too excessive to maintain its circumferential speed, as well as to reduce power consumption for operating the cutter.

Characteristics

1. Reduces by 30% the amount of electrical power necessary to operate the machine by optimizing the rpm of the cutter on the outer circumference.
2. Improves by 25% the excavating speed by reducing the burden on the cutter bit in the inner circumference during ground excavation and increasing the aperture ratio.
3. Improves boring operation rate by preventing problems caused by clogging of soil onto the central part of the cutter.

These effects have been confirmed through verification tests conducted using simulation experiment machines (Fig. 2).

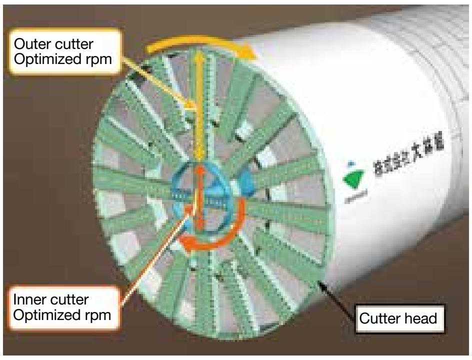

Fig.1 Cutter rotation frequency

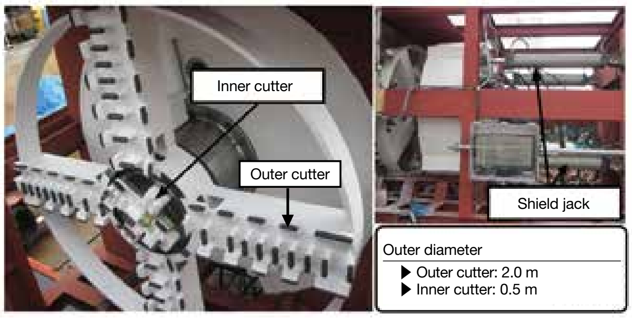

Fig.2 Verification tests

Construction of an underground discharge duct with prefabricated steel-concrete composite segment rings along a 3D composite curved path

Satoshi HASHIMOTO ► TAISEI CORPORATION

When constructing an entrance shaft for shield tunneling in an urban area, inevitably the project faces many difficulties due to the limited land acquisition and restrictions from underground structures, therefore complicated alignment for tunneling (sharp curves and steep slopes) must be planned. The solution generally used to overcome these problems is to build a rectangle box structure of cast-in concrete.

To curtail the maintenance costs for facilities with complex structures, alleviate requirements for skilled manpower for construction, and minimize the risks of quality and safety as well as to shorten construction periods, we have successfully developed a new unique technology for a shield project planned by Kobe City for the first time. The fundamentals of our technology are as follows: steel-concrete composite segment rings are assembled above ground with external bolts, and the rings thus assembled are introduced underground to form the discharge underground duct.

Photo 1 3D curved path of a discharge conduit

Photo 2 Assembly situation of composite segment rings

Shaft type remote control underwater machine T-iROBO UW

Motoaki MIZUNO ► TAISEI CORPORATION

T-iROBo-UW is a construction machine which, with an underwater operating unit consisting of a hydraulic shovel attached to the shaft, can be manipulated by remote control. The shaft type-configuration makes it possible to locate with ease the coordinate position of the machine underwater. With integration of imaging technology, the operation underwater is able to meet needs on a practical level. When changing attachments, even an ordinary operating machine can perform various types of work.
T-iROBO UW was launched for the project of reconstructing the Amagase Dam for which currently a tunnel-type flood control system is being constructed to improve irrigation facilities. Through this project, the T-iROBo-UW system was demonstrated to be a revolutionary way of underwater construction to shorten the construction period and to improve safety.

Fig. 1 Operation in the remote control room

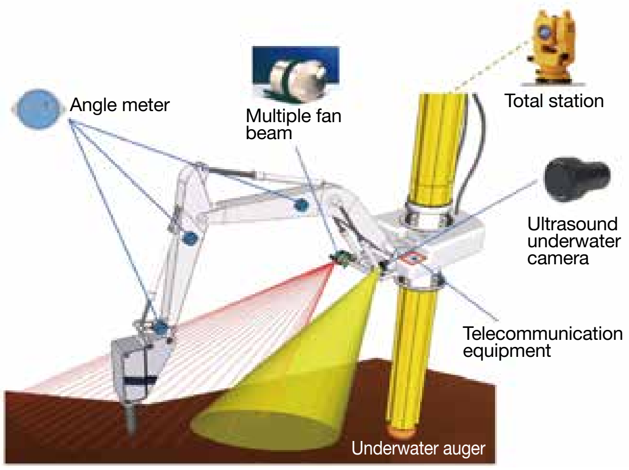

Fig. 2 Overhead view

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