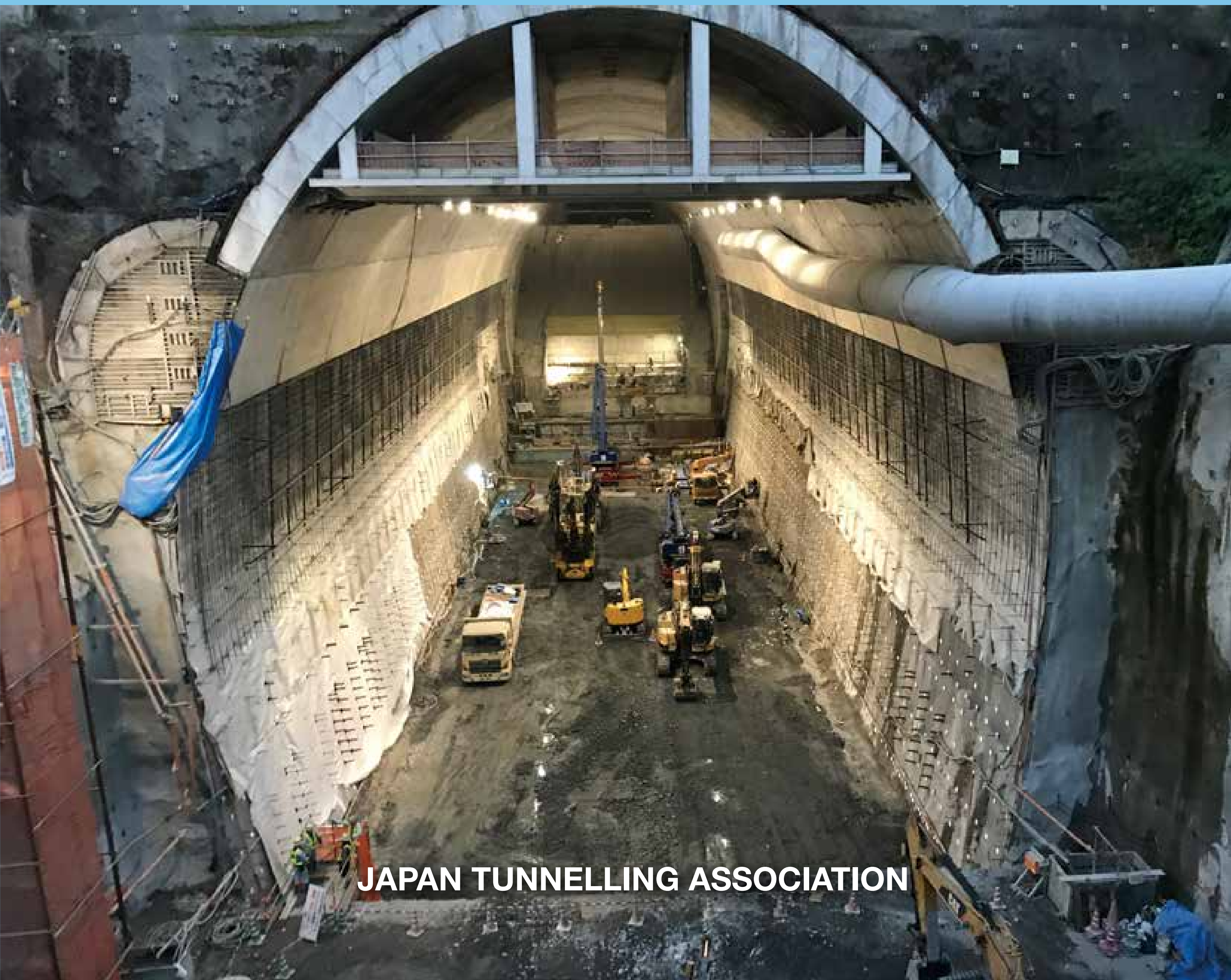
Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2022



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 2022 edition of Tunnelling Activities in Japan, Japan Tunnelling Association (JTA)'s biennial publication. The number of tunnel construction projects in Japan is still high, as various technical challenges being overcome for Shinkansen, expressways, and water and sewage projects.

Technology tried and proven during such domestic projects are utilized overseas, and Japan remains as one of the leaders of global tunneling technology.

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 tunnel design and tunneling technologies in resent years has made it possible to construct long tunnels and large section tunnels safety and economically, even under 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, there are many cases in which construction works 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, being built in soft ground and needs due consideration to living conditions of the surrounding houses, 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 fulfil the specific requirements for construction of urban tunnels.

In addition, in recent years, Japanese tunnel technology has been making use of new technologies such as ICT-based measurement systems, AI and robotics.

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.

KIKUKAWA SHIGERU

President
Japan Tunnelling Association

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Tunnel Activity 2022 Overview

1. Preface

The number of yearly tunnel construction projects, such as the Shinkansen, expressways, and water supply and sewerage, remain high in Japan. These constructions are done while resolving technical issues such as complicated geological and soil conditions and proximity to existing constructions.
While such progress is made, many tunnels in Japan were built during the period when Japan's economy was boosting. Tunnels surviving their 50th year are increasing. Need for maintaining and managing such tunnels is becoming larger, in a shrinking economy with a smaller pool of engineers. Japan's tunnels are being built and maintained under such severe conditions.
This publication introduces latest projects and new technology to overcome technical issues.

2. Tough Geological Conditions in Japan

In a global view, Japan is one of the smaller island countries with a total of 380,000km^2 national land, of which more than 70% is mountainous. Almost 130 million people live in Japan, where habitable land is extremely scarce. Major cities, such as Tokyo and Osaka, are overcrowded, and most of the space above the ground is used. Many social infrastructures are built under ground. As major cities are scattered around the country, travelers must reach them by going through steep mountains and straits, making the need of tunnels naturally high.

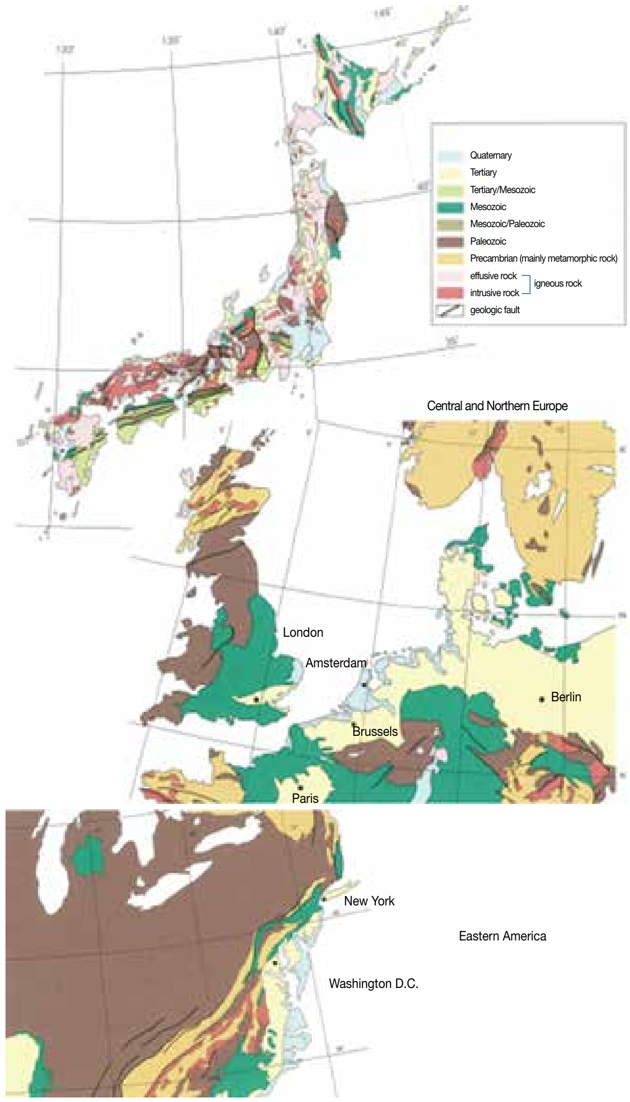


Fig.-2.1 Differences of Geology of Japan and the Western world

Photo-2.1 A Tunnel Face Sample in Japan with Soft and Hard Ground

Fig.-2.2 Advanced Usage of Underground Space in a Large City (Around Iidabashi station, Tokyo)

However, Japan is one of the countries most ill-fitted for tunnel construction. The Japanese Archipelago sits at the point where the Pacific and Philippine Plates meet, making the geological structure of its land significantly complicated compared to Europe or America (Fig.-2.1). In Japan, it is common to see a different geology every 1m of excavation, with hard and soft rock mix showing in one tunnel face (Photo-2.1). The plains surrounding major cities are created by deposits of newer geological eras, more often being soft ground. The underground space of such areas is already highly used for social infrastructure such as underground railways, water supply, and sewage. When newly constructing underground, the project would require building structures narrowly adjacent to existing constructions within the soft ground (Fig.-2.2).
To make a long story short, Japan has very severe natural ground conditions among the world, with high needs of underground usage. So, development of greatly advanced underground construction technology has been and will be critical for successful tunnel projects in Japan.

3. Current Tunnel Situation in Japan

There are many underground infrastructures built in Japan, and steady investment is made to maintain and grow the domestic economy, as well as creating safe and secure land (Fig.-3.1). After peaking in 1995, investment in infrastructure dropped slowly year by year, since the government restrained public investment. Recent years see increase of in

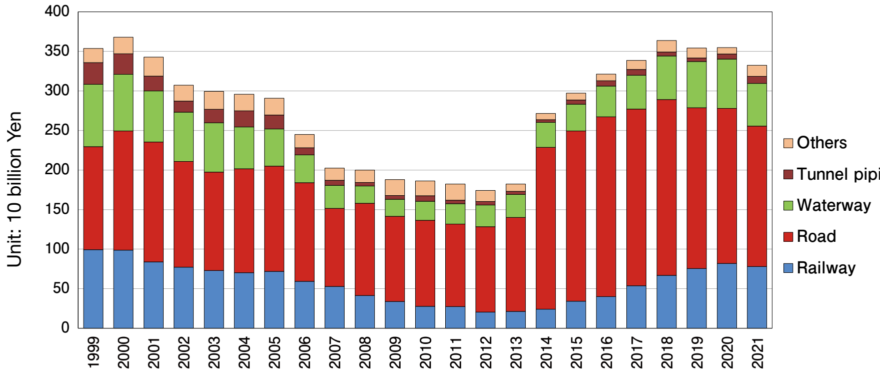


Fig.-3.1 Trend of construction investment in tunnels and underground space

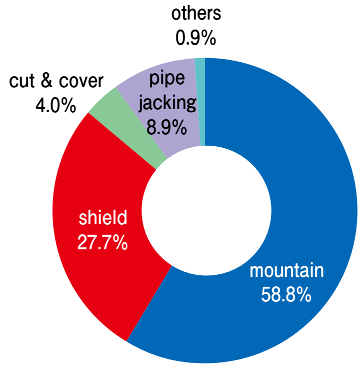


Fig.-3.2 Ratio by Tunnel Construction Method

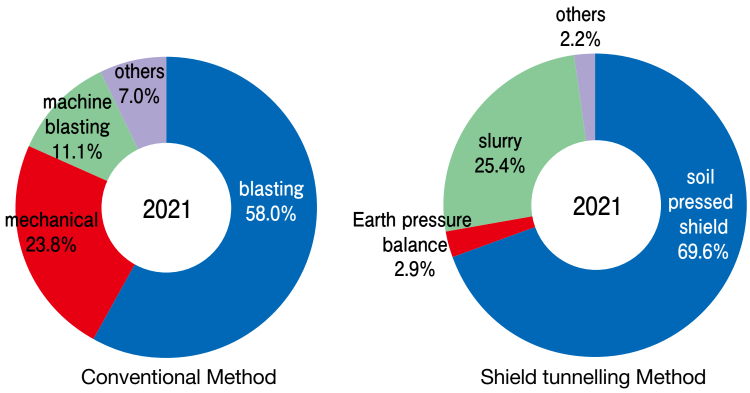


Fig.-3.3 Ratio of Tunnel Construction by Method

investment due to reconstruction efforts starting in 2014 after the Great East Earthquake.

Fig.-3.2 and 3.3 shows the trend of construction investment in tunnels and underground space by type. Mountain tunnels are 58%, with 58% of that using blasting. Shield tunnels consist of 24% of all constructions, and 70% of that use soil-pressed shield method.

4. Current Situation of Tunnel Maintenance and Management

Japanese tunnels were most constructed during the period of high economic growth, with many tunnels lasting for more than 50 years. Tunnel maintenance and management is becoming a large issue. Current situation of road tunnels and railway tunnels are as follows:

As of 2020, there are approximately 11,000 locations with a total of 5,100km of tunnels built in the road system (Fig.-4.1). The percentage of tunnels over 50 years will increase to around 50% by 2033.

The revision of the Road Traffic Act in 2014 requires all road tunnels' total lining surface to be visually checked onsite at least once in five years.

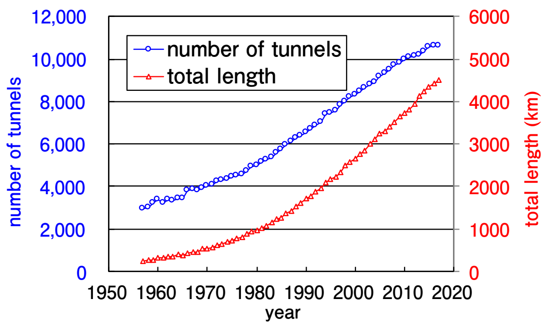


Fig.-4.1 Number and Length of Road Tunnels in Japan

(2) Railway Tunnels

As of 2020, the total length of railways owned by the seven JR group companies (former national railway) has become 19,791.60km. There are 3,494 tunnels, consisting 2,420km of that distance (*). The ratio of tunnels more than 50 years old is almost 60%.

There are directions by the Ministry of Land, Infrastructure, Transport and Tourism (MILT) determining the technical standards of railways, and these directions state the frequency of inspections. Regular inspections (Standard General Inspection) must be held within two years. In-depth inspection (Special General Inspection) must be held within 10 years for Shinkansen, and within 20 years for other railway tunnels in addition to regular inspections.

＊ Annual Railway Statistics Report (2020), MILT

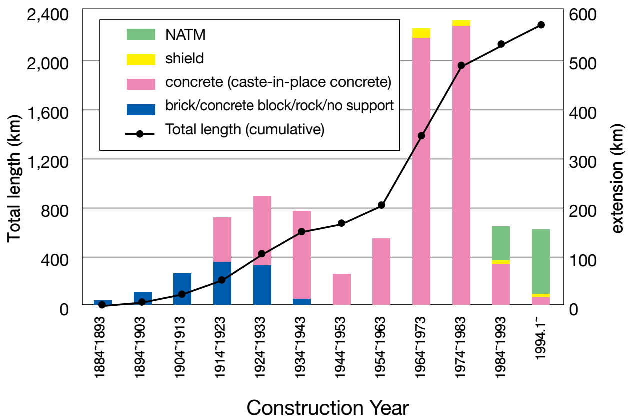
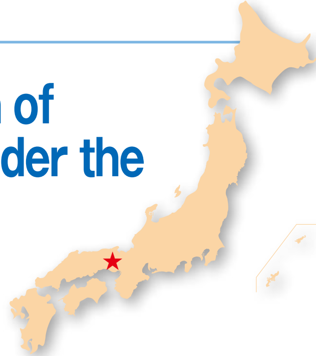


Fig.-4.2 Number of tunnels constructed by the seven JR companies (former national railway) by year (as of 2002)
Source:"Tunnel Library 14 Tunnel Maintenance in Japan", Japan Society of Civil Engineers, July 2005



Construction of a Watertight Tunnel in Consideration of Environmental Protection for Wetland Registered Under the Ramsar Convention

—The Hokuriku Shinkansen, the Miyama Tunnel—

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1. Introduction

The Hokuriku Shinkansen, which has a 690km route from Tokyo to Osaka, is currently being developed for a 125km route between Kanazawa Station and Tsuruga Station. The Miyama Tunnel is a mountain tunnel which has 768m length and a double track section. The Shinkansen route was changed since it locates near Nakaikemi Marsh which was registered under the Ramsar Convention in July 2012. The drilling of the tunnel was started by NATM in January 2019 and completed in August 2020 (Fig.1).

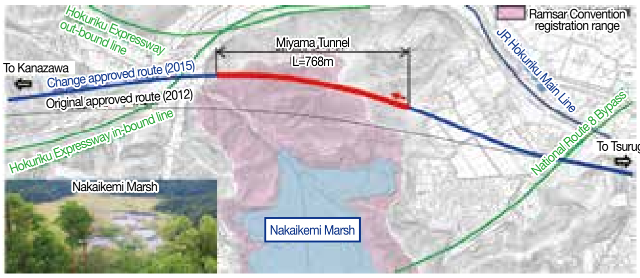

Fig. 1 Miyama Tunnel Route plan drawing

2. Feature and plan of tunnel

A feature of this tunnel is the presence of multiple active faults due to past active fault movements and crustal movements. In terms of the environment, consideration should be given to the diverse waterside environment of Nakaikemi Marsh and the growth of diverse flora and fauna. As for the excavation plan, we approached to preserve the wetland environment. To deal with complex lithofacies changes in which small-scale fracture zones repeatedly appear, we took balance excavation safety and economic efficiency (Fig.2). The following five items are representative examples of environmental protection measures taken for wetlands registered under the Ramsar Convention.

(1) Selection and change of Shinkansen route

We studied the route for two years to reduce the impact of Miyama tunnel construction on the surrounding environment. We concluded to horizontally move the route by around 150m further away from the wetland and vertically move the route by around 20m higher to prevent the lowering of groundwater level. (Fig.1,3)

(2) Continuation of monitoring survey

In order to properly assess the impact on the wetland environment, we are conducting monitoring surveys before, during, and after construction. We disclose the contents and results of the survey and follow up after gathering information such as opinions from stakeholders.

(3) Utilization of circular cross section watertight structure

After the construction of the tunnel, we utilized a watertight structure that covers the entire circumference with a waterproof sheet which has 2.0mm thickness to permanently prevent the ingress of groundwater into the tunnel. Since water pressure acts on the tunnel due to this structure, we used a circular cross section in lieu of horseshoe-shaped cross section which is common in mountain tunnels to reduce the lining thickness. (Fig.3)

(4) Implementation of advanced survey boring

As a countermeasure against sudden spring water, we conducted advanced survey boring to collect cores to grasp ground information and the appearance of spring water in advance. Once spring zone would be discovered, we will study the implementation of water reduction.

(5) Dealing with the impact of tunnel excavation

In case the water level drops during tunnel excavation, we would take an emergency measure to restore the water level. We planned to restore the water level by recirculating the natural flowing water in the downstream area as an alternative water source. We also took into account the contamination of species that may affect the ecosystem,

Fig. 2 Complex changes in the lithology of the tunnel face

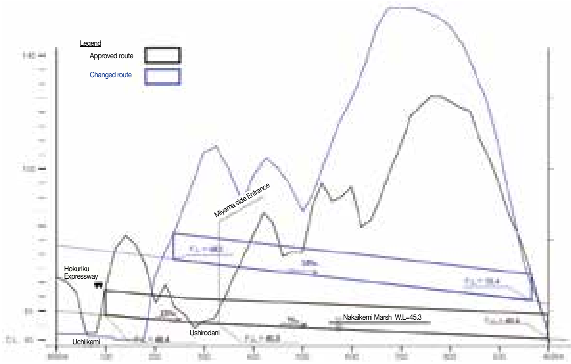

Fig. 3 Longitudinal section of the Miyama tunnel route

3. Construction result

As a result of taking various environmental protection measures, no significant impact on the wetland environment due to the tunnel excavation was confirmed. As of October 2021, we have not conducted the water level restoration. We will continue the post-construction monitoring surveys and do effort to protect the environment of wetlands registered under the Ramsar Convention.

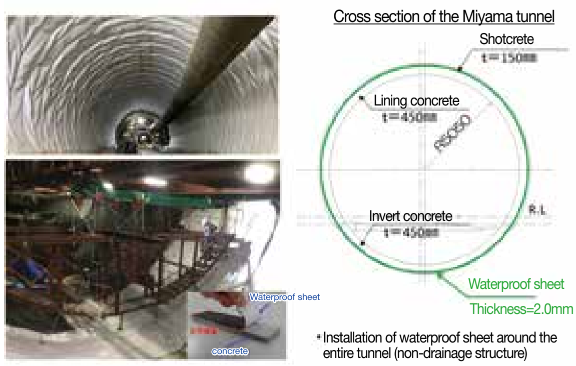

Fig. 4 Waterproof sheet and circular cross section (watertight tunnel)

2

Breakthrough of a Long Tunnel by Geological Evaluations Combined with Various Types of Forward Exploration

— Hokuriku Shinkansen New Hokuriku Tunnel (Okunono Construction Area)—

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Japan Railway Construction, Transport and Technology Agency
Takeshi KOYAMA ▸ Site Manager, Obayashi Corporation

1. Introduction

The Hokuriku Shinkansen is a 690 km-long line that starts in Tokyo and ends in Osaka City via Nagano, Toyama, and Obama. The Okunono section of the New Hokuriku Tunnel is a 4,880-meter-long middle section of a 20 km-long mountain tunnel located in Fukui prefecture. Construction was done using a working pit (inclined shaft). The cross-section of the excavation was approximately 70 m^2, using the full-sectional method with an auxiliary bench. Digging was done by blasting method, with continuous belt conveyor method used for shedding. Eleven faults were expected in the construction area (shown in Fig. 1), with widths ranging from a couple of meters to maximum 80 m. The natural ground was expected to be fragile with many fractures developed along the faults, with concerns of sudden water inflow especially in the area of chert.

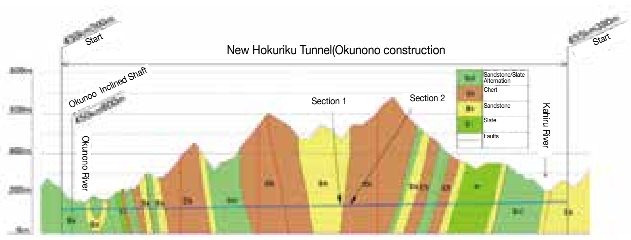

Fig. 1 Longitudinal Profile of the Geology

2. Overview of Exploration Methods

As shown in Table 1, three types of forward exploration were carried out to understand the geological conditions in front of the cutting face.

Tab. 1 List of Forward Probe

List of Forward Probes			Notes
Name	Probe depth/number	Results	
medium-length non-core exploration drilling	150-180m/time 34 times (full length)	Index-value of energy	Down-the-hole method Water-pressure hammer boring
short-length non-core exploration drilling	30-50m/time 120 times (full length)	Speed ration of normalized drilling Prediction of water inflow	Percussion drilling
Seismic Survey	150-180m/time 33 times (full length)	Prediction of water inflow Reflection surface V_p/V_s ratio	TSP203

3. Prediction of Natural Ground using Forward Exploration Results and Actual Digging Results

Conditions of the natural ground 150 m ahead were predicted by combining result from the non-core exploration drillings and in-pit elastic wave survey described above. The results showed multiple sections of fragile terrain including fault fracture zones, fracture concentration zones, and stratigraphic boundaries, as well as sections with high risk of sudden and heavy water inflow. Among the potentially bad sections, the following two (Fig. 1) were unique in the way they clearly showed the characteristics from the forward exploration results.

Section 1: 453km185-215m (L=30m)
Section 2: 453km250-265m (L=15m)

Table 2 is a comparison between predicted and actual natural ground conditions for sections 1 and 2.

Tab. 2 Expected and Actual Conditions of Natural Ground

	Kilometrage	Short to Medium-scale non-core drilling logging	Seismic Survey	Condition of Natural Ground: Expected	Condition of Natural Ground: Actual
Section 1	453km 185 ~ 215 m	Chert dominated ground Equivalent to IS - IN-1 Water: 1,000L/min Water pressure: 0.75MPa	VP downward Focus on reflection surface V_p/V_s reduce	Mainly chert Cracks, exfoliation, and other surface discontinuities is significant Possibility of water high due to being a valley	Mainly fragile chert Face of digging had a lot of sediment and caused much exfoliation Digging face had 40L/min water at maximum
Section 2	453km 250 ~ 265 m	Chert and Alternation mix Equivalent to Is to IN-2 Water: 450L/min	Lot of change in V_p Dense reflection surface V_p/V_s slightly changed	Mix of chert and sandstone/slate alternation A lot of cracks, exfoliation, and other discontinuities Low possibility of high-level water inflow	Mainly chert with many cracks Excavation face could not stand alone Digging face had water 20L/min at maximum

3-1 Section 1: 453km185 ~ 215m

This section raised concern of sudden water inflow. The water inflow rapidly increased to 1,000 L/min. during logging. Additional measurements of the inflow rate and inflow pressure were done. Judging from the results, due to the predominantly fractured chert soil, there was a very high possibility that a large amount of water inflow would occur when the tunnel face was reached.

The actual site was dominated by fragile chert, and the maximum water inflow was 40 L/min. at the mirror surface. A lot of the dirt showed sedimentation especially on the face of the excavation with many fission exfoliation shown in Photo 1.

The water inflow from drilling and logging holes decreased from 1,000 L/min. to 500 L/min. as the face progressed, and the water inflow on the mirror surface during excavation was minimized by draining water in the forward ground using medium-scale non-care drilling and logging.

3-2 Section 2: 453km250 ~ 265m (L=15m)

This section was feared to be fractured ground. Combining results of various tests, unstable ground was expected to be located near the boundary between the multi-fractured chert and the soft sandstone/slate alternation.

The actual ground was a multi-fractured chert ground with small water inflow, but as seen in Photo 2, the small amount of water caused the face to be very unsustainable.

In the actual construction, the core was left during excavation to stabilize the mirror surface. The water inflow at the face was minimized by draining water during drilling.

4. Conclusion

Bad ground conditions were predicted in advance with a high degree of accuracy by evaluating the ground using a combination of various types of frontal surveys. The excavation was conducted safely without any delays by considering appropriate support patterns and auxiliary construction methods beforehand as well.

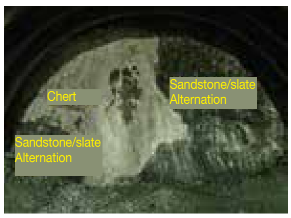

Photo 1 Face Condition (453km200m)

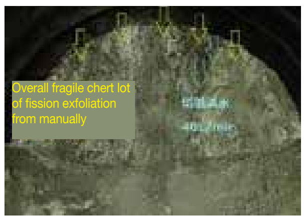

Photo 2 Face Condition (453km260m)

Excavation directly under the main road in an urban area using the mountain tunnelling method with pipe roofing

— Kyushu Shinkansen West Kyushu Route, Isahaya Tunnel —

Shinichiro HARI ▸ Manager, Nagasaki Construction Site Office
Japan Railway Construction, Transport and Technology Agency (JRTT)

Introduction

The Kyushu Shinkansen (West Kyushu Route) is a high-speed rail line connecting Fukuoka and Nagasaki prefectures in Kyushu, Japan. An extension of 67 km between Takeo Onsen and Nagasaki is currently under construction and scheduled for completion in fall of 2022. The Isahaya Tunnel is a 230-meter-long tunnel that passes through a busy national highway with a small soil cover of about 3.5 meters. The ground is mainly composed of a tuff breccia layer containing hard gravel (Fig. 1 and 2). In order to minimize the impact of the tunnel excavation on the road traffic, the tunnel was excavated by the mountain tunneling method using pipe roofing to prevent the road surface from sinking. This paper introduces the features of pipe roofing in this tunnel.

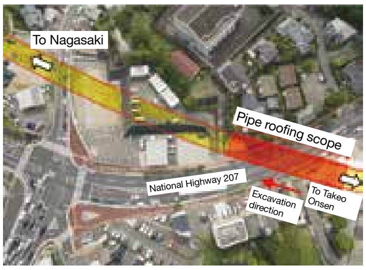

Fig. 1 Isahaya Tunnel plane figure

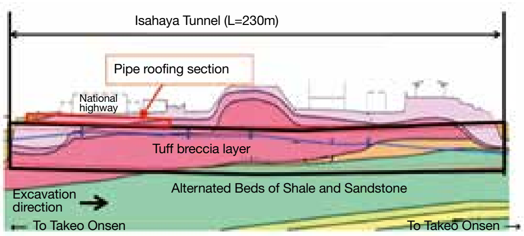

Fig. 2 Isahaya Tunnel longitudinal view

1. Construction plan for national highway intersection

The national highway section has a traffic volume of 25,000 vehicles per day, as well as many buried pipes for water, sewage, electricity, communication, and gas. In order to avoid the social impact of traffic restrictions on the main road and the replacement of various buried pipes, the mountain tunneling method was applied to this tunnel.

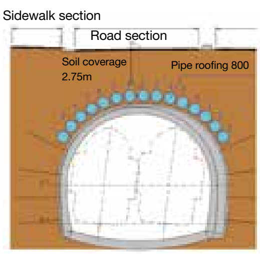

Fig. 3 Cross-section figure of the Isahaya Tunnel's national road area

The pipe roof method (Φ 800mm, L=60m x 15 pipes) was adopted as a countermeasure to prevent the road surface from sinking and to preserve the function of the buried pipes (Fig. 3).

2. Features of pipe roofing used in this tunnel

When the pipe roofing method is applied to tunnels with small soil cover, there is concern about water inflow through the gaps between adjacent pipe roofs (steel pipes) and into the ground. In order to prevent this problem, the conventional method involves the installation of junctions between adjacent pipe roofs and excavating while joining them to eliminate the gaps between the pipe roofs. However, the ground to be excavated for this tunnel is composed of hard gravel (uniaxial compressive strength of 130 MPa or more, gravel content of 40-50%) with a diameter of 10 cm to 100 cm and soft substrate. Therefore, it was assumed that if the joint was disturbed by huge gravel, the joint would break, and excavation would become impossible.
Therefore, it was necessary to develop an alternative method to close the gap between the pipe roofs instead of using joints. In order to solve this problem, we devised the backfill lapping method, which consists of lapping the backfill instead of using joints. In this method, the distance between the pipes is set to 5 cm, and the backfill of the preceding pipe roof is cut by the following machine while excavating, and the backfill materials are lapped together to increase the tightness by filling the void between the pipes (Fig. 4).
The pipe roof construction requires high-precision excavation management, so a machine that can make real-time directional corrections within a range of ± 1.5° in the vertical and horizontal directions was used, and an ICT-based 3D propulsion accuracy management system was developed to achieve high-precision excavation management.

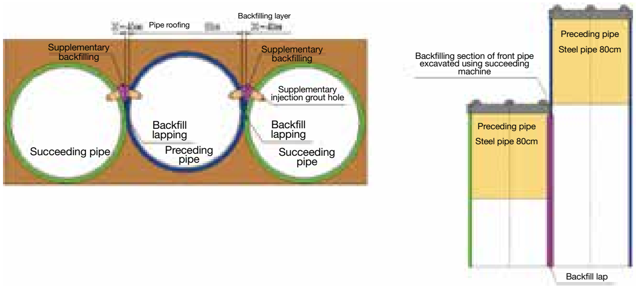

Fig. 4 Backfill lapping method overview

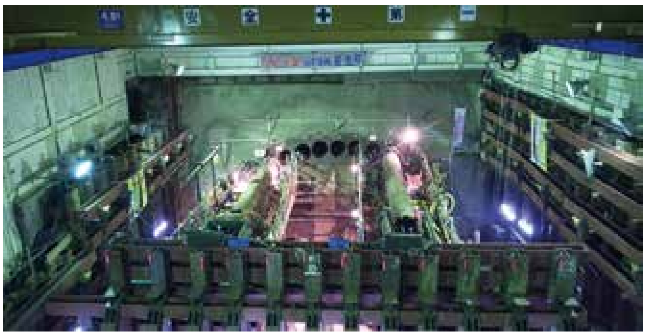

Photo 1 Pipe roofing scene

Excavation of a Large-Section, Deep Shaft Using a Diaphragm Wall and Chemical Grouting

— Chuo Shinkansen Meijo Emergency Exit —

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Jiro KOMATSU ▶ Chief, Chuo Shinkansen Construction Department, Chuo Shinkansen Promotion Division, Central Japan Railway Company
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Yasutaka IMANAKA ▶ Deputy Director, Design Department 1, Production Engineering Division, Civil Engineering Headquarters, Obayashi Corporation

The Chuo Shinkansen is a line built to create a dual transportation system of Japan's main arteries, which has long been carried by the Tokaido Shinkansen (Tokyo to Osaka). (Fig. 1) It is planned to construct the shield tunnels deep underground (depth of 40m+) in urban areas that are already highly urbanized. The launch shaft for shield tunnel nearest to Nagoya Station is the Meijo Emergency Exit. (Photo 1)
The emergency exit is used for ventilation and maintenance work in the tunnel in normal operation, and as an evacuation route for passengers in case of emergency.
The Meijo Emergency Exit is a cylindrical shaft with a depth of approximately 89m and a diameter of approximately 38m. The construction was carried out using the open-cut method with a RC diaphragm wall of approximately 130m in length. After excavating to a depth of approximately 50m, water inflow occurred from around a blocked observation well, but the excavation was successfully completed by carrying out water sealing work. This paper is an outline of the water inflow and the processes to complete the excavation by implementing water sealing work.

Fig. 1 Chuo Shinkansen planned route

Photo 1 Meijo Emergency Exit

Countermeasures for ground heaving

It was planned that the groundwater level was lowered by pumping out the pore water in the aquifer just below the diaphragm wall. In order to reduce the amount of pumping, a single row of injection holes with a spacing of 0.8m was placed into the aquifer just below the diaphragm wall. And chemical grounting was carried out.

Water inflow

When the excavation proceeded to approximately 50m, water inflow occurred around the observation well, which had already been blocked. In order to estimate the cause of the water inflow, an acoustic tomography survey was conducted. As a result, it was found that the unevenness and inclination of the stratum were larger than expected, which led to the disagreement of the watertight packing of the well closure. It ended in forming the water path.

Countermeasures for water inflow

As a result of acoustic tomography, it was decided to construct a cutoff wall inside the diaphragm wall by chemical grouting, because the water path was considered to exist just below the diaphragm wall due to the unevenness of the stratum. (Fig. 2)
The purpose of chemical grouting is not to "reduce" the water inflow into the shaft, but to "stop" it. The volume per step was increased compared to that of normal chemical grouting because of the large depth and high artesian water pressure. In addition, thorough construction management was carried out by "(1) drilling of the injection hole by two-stage excavation and confirmation of the drilling position by gyroscopic survey" to accurately inject the chemical solution into the deep area and "(2) confirming the injection effect via check injections to maximize the effectiveness of the chemical grouting".
In particular, in (2), the injection pressure of all the holes located in the middle of the three rows was checked(ref. Row C in Fig. 2), and check injections were carried out in the steps where no pressure increase was observed.
The check injections ware able to compensate for the lack of improvement, and the upward trend of pressure was confirmed in all of the injection areas.
As a result of the pumping test, the amount of pumping required for drawdown was 1.2 L/min on average, which was very small, and it was considered that a good quality cutoff wall could be constructed by chemical grouting.
After the excavation was resumed, the excavation was completed to approximately 89m without any water inflow.

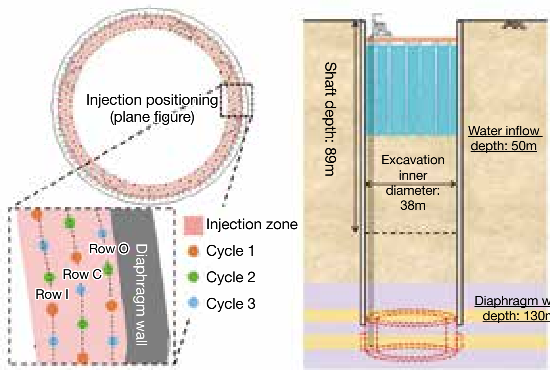
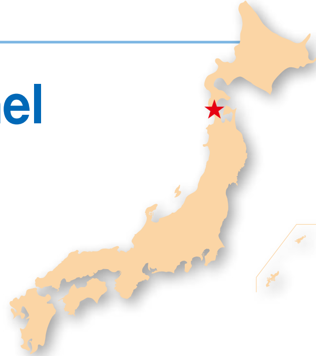


Fig. 2 Chemical grouting schematic diagram



Repairing the Pilot Tunnel of the Seikan Tunnel
Tappi Pilot Tunnel Repair Works

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Introduction

The Seikan Tunnel is a long undersea tunnel with a total length of 53 km 850 m. The undersea section of 23 km 300 m consists of three tunnels (the main, working, and pilot tunnels). The deepest part of the tunnel is 240 m below the sea surface and is subjected to strong water pressure of up to 2.4 MPa. The tunnel is used under unique conditions as it is constantly exposed to strong water pressure and inexhaustible spring water from the seafloor. (Figure 1)
Due to the unique environment of the Seikan Tunnel, various measurements have been carried out continuously since its opening. A wide range of items is measured including the displacement of the inner space of the main, working, and pilot tunnels, the amount, pressure, and quality of water inflow, the neutralization and strength of the concrete, and the deterioration of the injection material. Significant changes were discovered at the pilot tunnel, and these changes had to be controlled through various measures, which is reported in this paper.

1. Background to the repair work

The 1km 050m area of the Tappi pilot tunnel showed periodical displacement measurements. From 1993 to 2011, a reduction in the inner space cross-section and a rise in the roadbed (300mm) were observed (Figure 2).
2. Design of the repair work
To fix the reduction in the inner space cross-section and a rise in the roadbed, the effect of rock bolts and invert concrete was verified by reproducing the deformation using numerical analysis. As a result, six rock bolts per section after removing the roadbed concrete was decided the best for minimizing the effect on the tunnel (the amount of internal air displacement).
As a result of the verification, the existing roadbed concrete was removed, and the invert concrete was reconstructed after the rock bolts were placed on the uplifted roadbed concrete. It was decided to manufacture the concrete on site because it took 90 minutes (23 km) to transport the concrete from the aboveground plant to the place where it was placed. Since the tunnel is too narrow to install a plant, the concrete was mixed on site using a small mixing machine. (Figure 3)
3. Conclusion
As a result of the repair work, the work was completed safely without any internal air displacement. Three years have passed since the repair work was completed, and no deformation such as internal air displacement or uplift of the roadbed has occurred.
We will continue to conduct follow-up investigations on the repaired roadbed in the future.

Fig. 1 Outline of the Seikan Tunnel

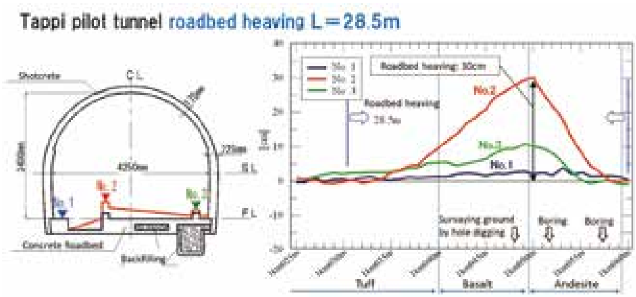


Fig. 2 Roadbed heaving

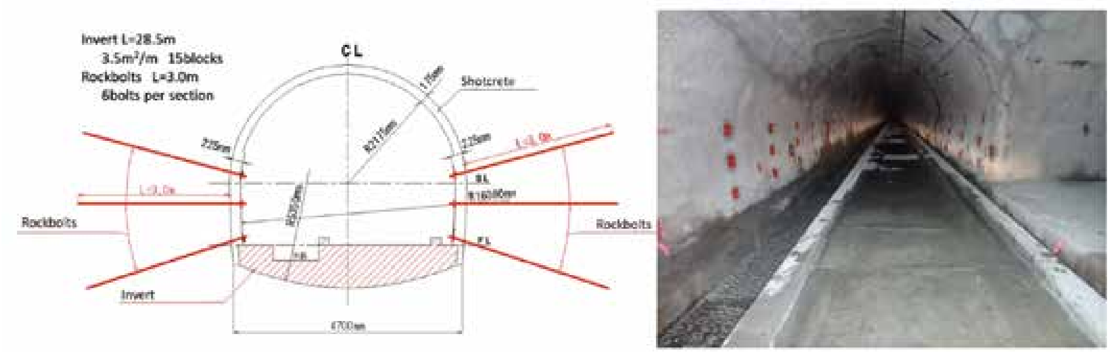


Fig.3 Section of repair works and Construction completion

A large-scale 920-meter-long subway station extension improvement project using the three-dimensional urban planning system" — Sengakuji Station, Toei Asakusa Line —

Takeshi HAYASHIDA ▶ Deputy Director,
Planning and Improvement Section, Construction and Maintenance Division
Bureau of Transportation Tokyo Metropolitan Government

1. Station improvement background

Sengakuji Station on the Toei Asakusa Line serves as a transportation node with excellent access to Tokyo's subway network and Tokyo International Airport. In the vicinity of the station, a new JR station has opened and large-scale development as an international exchange center is expected in the future.

Sengakuji Station is currently a box-shaped tunnel with two underground levels. The second underground level has two 5-meter-wide island platforms with four tracks, and the first underground level has separate concourses on the north and south sides. In addition, the station faces the problem of chronic congestion during rush hours, and the increase in the number of station users is expected to become even more pronounced as large-scale development progresses in the surrounding area.

Therefore, there is a need for a drastic improvement of the station, including the widening of platforms and improvement of elevator facilities, in order to improve the safety and convenience of the station.

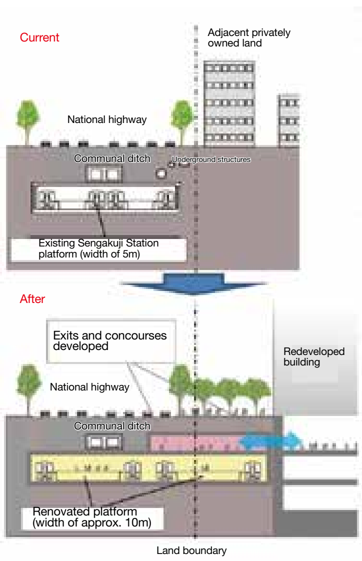


Fig. 2 Station renovation overview diagram

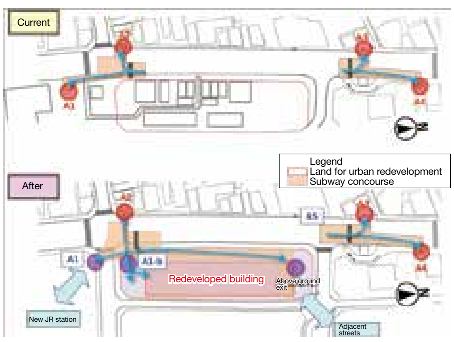


Fig. 3 Station exit development diagram

2. Station Improvement Plan

Securing sufficient space using the area under the road was difficult. The Bureau of Transportation of the Tokyo Metropolitan Government therefore decided to change the urban planning of Urban Area Rapid Transit Line 1 in the 920-meter section that includes Sengakuji Station, and to use the three-dimensional urban planning system to define the necessary area for the development of urban facilities, and to use part of the underground area of the urban redevelopment project site as the project space for the station improvement project. The width of the platform will be adjusted to accommodate passengers.

The platform width will be widened to about 10m to meet the service level of passengers and to minimize the scope of the renovation.

The station will have additional entrances and exits to form a new pedestrian network and enhance passenger routes, avoiding the constraints of important infrastructure such as the nearby national historic sites and the communal ditch and sewage line directly above the station.

In addition, in order to further improve the convenience of the station, the elevating facilities will be enhanced, and two barrier-free routes will be developed to allow passengers to move from the platforms to the ground level entrances by elevator.

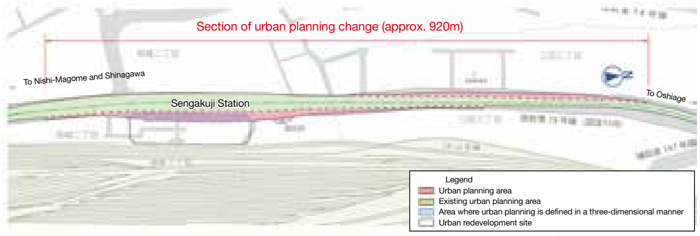


Fig. 1 Plane view of plan

3. Conclusion

Improving Sengakuji Station is a highly difficult construction project to be carried out in a narrow space while the subway is in operation. Furthermore, it is directly under the main road where there is a lot of traffic and congestion of underground structures.

This project will apply reinforcement methods to cope with structural changes due to the construction and removal of new structures, formulate a track switching plan to minimize the impact on railroad operations, and adopt a trenchless method under a national historic site.

Square Element Propulsion Method Applicable to Large-Section Horseshoe Tunnels in Trenchless Areas of Stations

Tatsuya SHIMOTSU ▸ Manager, Tokyo Regional Bureau, Tsunashima Construction Site Office
Japan Railway Construction, Transport and Technology Agency (JRTT)

Introduction

The Sotetsu-Tokyu Direct Line is a 10km long line that connects Sagami Railway, which operates mainly in Kanagawa Prefecture, and Tokyu Railway, which operates in southwestern Tokyo, and is under construction for completion in the second half of FY 2022. The Shin-tsunashima Station (tentative) to be built in Yokohama City will be an underground station with an island platform at a depth of about 35 meters, based on four levels. The majority of the station will be constructed using open-cut construction methods, but the 34.5-meter-long Tokyo side of the station, which is 240 meters long, will be constructed using trenchless methods because of the presence of solid buildings such as a hospital above ground (Fig. 1). This paper focuses on the trenchless method for the large section horseshoe tunnel.

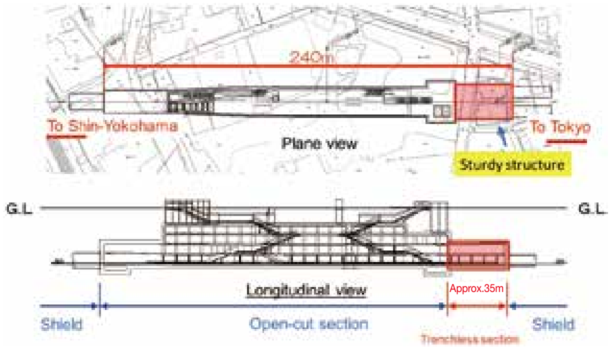


Fig. 1 Shin-tsunashima Station and Trenchless Segment Overview

1. Construction Plan for the Trenchless Section of the Station

To construct the trenchless section of the station, we adopted an advanced construction method for the outer shell in consideration of the geology and the impact above ground. Shafts in Japanese rail stations are set up on the departure and arrival sides, and the propulsion machines used to build the outer shell are recovered and reused in the shafts on the arrival side. However, in this construction area, it was impossible to install a shaft at the arrival side due to the condition of the ground, so the recovery of the propulsion system presented an issue. To address this issue, we developed a self-propelled truck to retrieve the propulsion system, which enabled us to reuse the propulsion system without a shaft (Fig. 2).
In addition, the square element propulsion method, which is a new technology, was adopted in order to achieve a horseshoe cross-section with a longer construction length and larger cross-section than the conventional method. A square element is a box-shaped cross-section (1000 mm x 1000 mm) of steel plates welded together to form a single element, with concave and convex joints connected. The construction sequence is shown in Fig. 3.

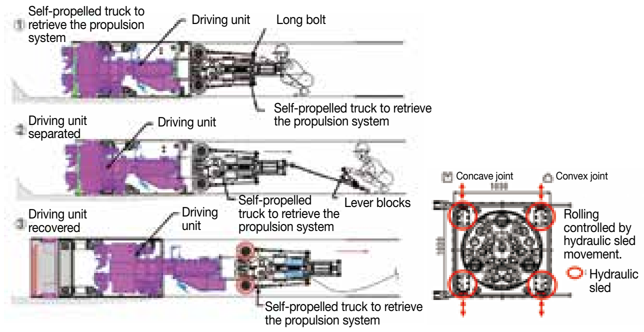


Fig. 2 self-propelled cart (left) and hydraulic correction jack (right)

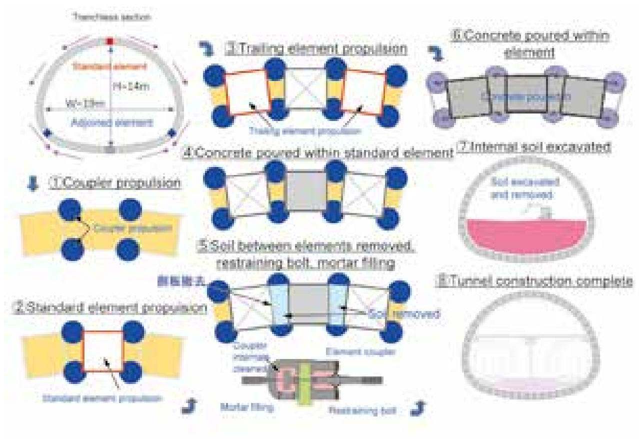


Fig. 3 Square element construction sequence

2. Longer distances and horseshoe-shaped cross section

In the construction of a square element, the propulsion machine is driven into the ground by extending the pressing jacks in the launching shaft, and the subsequent elements are connected one after another. For rectangular element propulsions, the position of the propulsion machine becomes the position of the main structure, so strict excavation accuracy is required. In this construction section, the excavation length was long, and each element had a different angle in a horseshoe shape, so it was important to ensure the excavation accuracy. Therefore, in order to secure the digging accuracy, a new hydraulic correction jack (Fig. 2) was added to the propulsion system to control and manage not only the vertical and horizontal displacement, but also the rolling.

3. Construction results

As a result of the above measures, the 42 square elements were constructed within the control values. Internal excavation after the construction of the elements was also completed, but there was little leakage into the interior and the impact on the ground surface was minimal. We believe that this will help expand the applicability of the trenchless method in the construction of large cross-sectional underground spaces.

8

The work of large-scale cross-section expansion of underground station constructed with pneumatic caisson method

— Minami-sunamachi Station, Tokyo Metro Tozai Line —

Keisuke OKANOYA ▸ Staff, Tokyo Metro Co., Ltd.

Introduction

In order to address the congestion on platforms and train delays during rush hours on the Tokyo Metro Tozai Line, underground stations with one island platform and two tracks will be upgraded to two platforms and three tracks, and elevating facilities and ticket gates will be relocated for smoother passenger flow. The total length of the project is about 430m, and the new structure will be constructed by excavating to a depth of 14m using the open-cut method (Fig. 1).

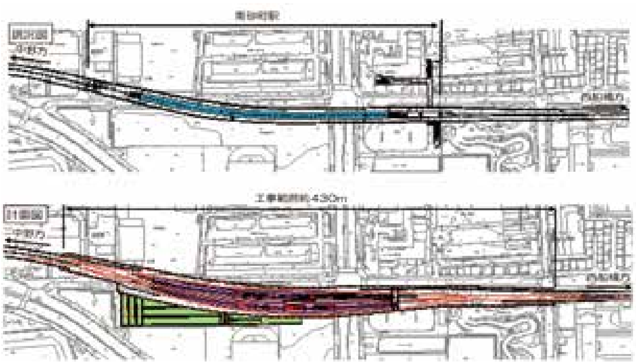


Fig. 1 Current and planned view

Photo 1 Underground RC diaphragm wall construction conditions

Photo 2 Ground improvement construction from within the station

Construction challenges

Minami-sunamachi Station, which was a canal at the time of construction, was built using the caisson method, and the surrounding ground was extremely soft (N value = 0~1). Therefore, measures to control the displacement of the surrounding ground and existing structures (canals) are required for station improvement.

Construction outline

The station improvement work was carried out in the following manner, with underground diaphragm walls and ground improvement as the main measures against the extremely soft ground (Fig.2).

① Prior to the construction of the new structure, the underground obstacles in the excavated section were removed and the earth retaining wall and intermediate piles were constructed in advance. The retaining wall is an underground RC diaphragm wall that can be used as the main body. The leading element (width: 1.9m, depth: 44m) and the trailing element (width: 6m, depth: 17m) are arranged in a comb structure and connected (Photo 1).

② The excavation began after improving the ground to prevent post-excavation heaving.

The thickness of the ground improvement was 2m, and the improvement ratio was 50% in the longitudinal direction of the railroad line (Photo 2).

③ After excavation to the specified depth was completed, the new structure was constructed and the existing structure that interfered with the construction limit was removed.

④ The tracks were switched, and a two-sided, three-track system was achieved.

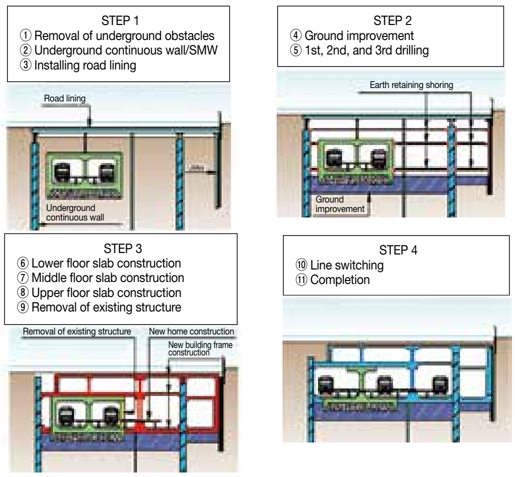


Fig. 2 Construction steps

Construction results

During the construction, measurement and control of the surrounding ground and existing structures were carried out, and there was no impact on the surrounding ground during the construction of the underground RC diaphragm wall. The ground improvement also had minimal impact on the surrounding ground, but the existing structure showed a tendency to settle by 0.1~0.2mm/day when one machine was installed, and by 0.4~0.5mm/day when two machines were installed simultaneously.

This construction work was able to proceed without interfering with the business line by taking measures against the extremely soft ground.

Construction of a Mountain Tunnel under Obstacle-Spotted Areas on Sandy Ground with Overburden

— Shin Meishin Yokkaichi Tunnel —

Tetsuya YAMAZAKI ▸ Manager, Tunnel Research Office, Road Research Department, NEXCO Research Institute

1. Introduction

The Shin-Meishin Expressway Yokkaichi Tunnel is a 1,353m long expressway tunnel (inbound and outbound). The geology of this tunnel consists mainly of soft layers and unconsolidated ground, such as consolidated silt, sand and gravel, and fan deposits. The minimum soil cover is only 9m, and the ground surface is dotted with obstructions such as golf courses, roads, and rivers.

Therefore, surface subsidence measurements and displacement measurements were taken at various locations to monitor the impact on the obstacles.

Photo 1 Aerial view

2. Evaluating Face Stability by Measuring Preceding Settlement

Since the tunnel was mainly composed of unconsolidated ground and the soil cover was small, there was concern from the beginning that the face would become unstable. Therefore, it was necessary to understand the behavior of the surrounding ground due to tunnel excavation. To evaluate and monitor the stability of the ground in front of the face from inside the tunnel, a top-end leading subsidence meter was adopted, as shown in Figure 1. The relationship between the settled amount u calculated by this measurement and the position of the face is shown in Figure-2, using the displacement ratio R, which is calculated by dividing the settled amount u by the total displacement

As a result, the displacement ratio Ruf until the upper half passage is 10% to 20%. This result is small compared to the percentage of prior displacement, which is generally considered to be 30 to 50% of the total displacement. Thus, by measuring the leading displacement, which is not captured by the standard A-measurement, it is possible to measure the total displacement occurring in the ground. By actually measuring the total displacement, it was possible to evaluate the strain in the ground and more precisely determine the plasticization of the surrounding ground.

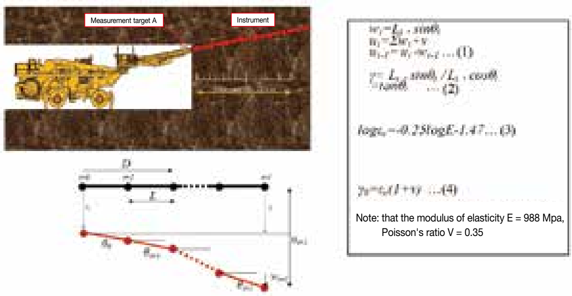


Fig. 1 Principle of the crown leading settlement measurement

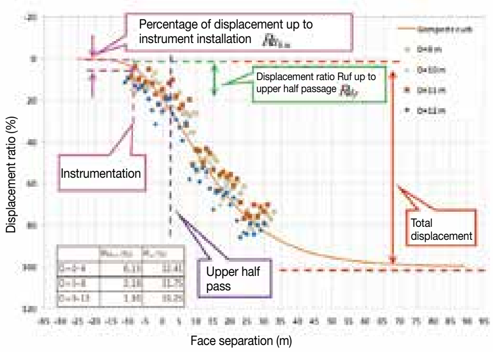


Fig. 2 Percentage of prior settlement (%)

3. Measurement of ground surface settlement of city streets

On the surface, the amount of settlement of the road surface was measured by live monitoring using a total station. The measurement results are shown in Figure 3. The maximum settlement was 22mm, and levels were kept at control level I without causing deformation such as sinking.

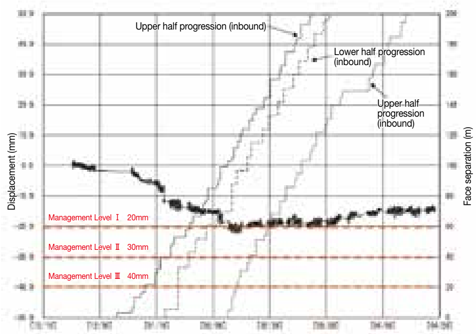


Fig. 3 Amount of subsidence of the ground surface directly under the municipal roadway Change over time

4. Measuring pipeline settlement

A ϕ 1500 mm hume pipe in service existed across the top of the tunnel, which was used for agricultural purposes, water supplies, and industrial water. Therefore, a settlement plate was installed at the top of the pipe before passing through the tunnel, and settlement measurements were taken to monitor the impact on the pipe. The measurement results are shown in Figure 4. The amount of settlement was kept to about 22mm by various measures to stabilize the face and to prevent water inflow. The maximum amount of settlement in the section parallel to the downstream tunnel was about 16 mm. This allowed construction to be carried out without damaging the function of the tunnel.

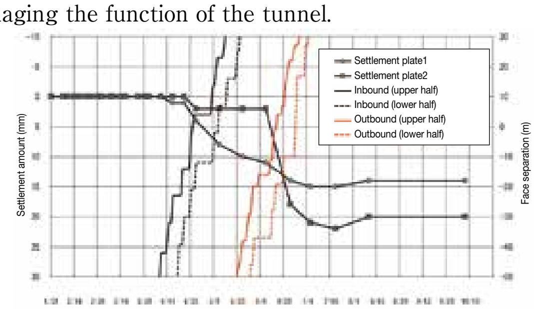
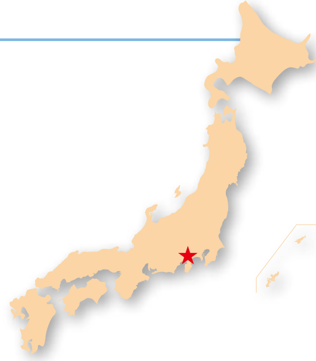


Fig. 4 Settlement plate measurement results

Mountain Tunnel Construction Using ICT

— Shin-Tomei Expressway Kawanishi Construction Yagayama Tunnel —



Kensuke MIYAZI ▸ Hadano Construction Office,
Tokyo Regional Branch, Central Nippon Expressway Company Limited

Naoki KANDOU ▸ Civil Engineering Department,
Tokyo Regional Branch, SHIMIZU CORPORATION

1. Overview

The Shin-Tomei-Nagoya Expressway Kawanishi construction project was designated as construction project making full use of ICT to improve productivity through the joint efforts of the contractor and the client. This section introduces an example of ICT construction in the Yagayama Tunnel.

2. Using ICT

ICT technology is being actively utilized in the construction of the Yagayama Tunnel at each stage of the work process. Table 1 shows a list of examples of how ICT was used. This section reports on the use of BIM/CIM in mountain tunnel construction.

Type of work	Details of efforts
Tunnel excavation	Reduction of excess excavation by automatic control system for angle of insertion
Shotcrete	Large-volume shotcrete using a liquid quenching agent
Lining Concrete	Efficient placement of lining concrete by automatic compaction system
Underground earthwork	Underground earthwork ICT construction equipment for information-intensive underground earthwork
Indpection	Remote inspection system to improve work efficiency
Inspecion and Maintenance management	Initial Inspection of concrete lining by mobile vehicle
Construction ~ Maintenance	Utilization of BIM/CIM in mountain tunnels

Table 1 List of ICT-based initiatives

3. Utilization of BIM/CIM in Mountain Tunnel Construction

(1) Construction efforts

A ground-based laser scanner was used to acquire point cloud data before and after the lining concrete was placed, which was superimposed on a 3D model to create a cross-sectional drawing, and the thickness of the lining concrete and the tunnel interior were measured for use by the client in the formwork inspection (Figure 1).

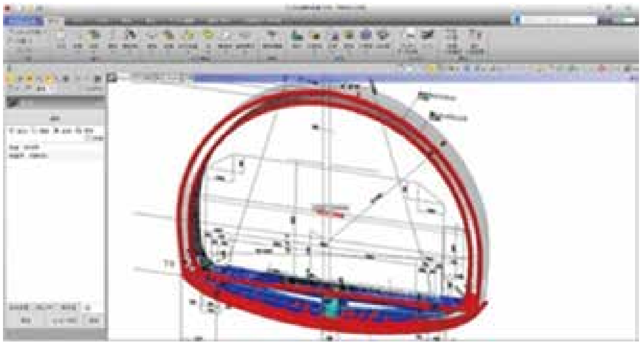


Fig. 1 Detection of finished shape by 3D model

(2) Handover to facility construction and maintenance

As part of the data handed off from civil engineering to equipment construction and maintenance management, we acquired point cloud data for the entire underground tunnel line, creating a 3D model, adding traceability such as construction information and inspection records to the BIM/CIM model as attribute information, and updated the data at each stage of construction (Figure 2). Centralizing and upgrading data in 3D in all processes from survey and design to construction, inspection, maintenance management, and renewal was expected to improve productivity.

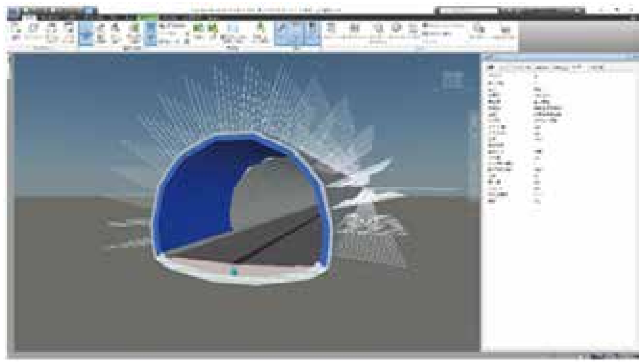


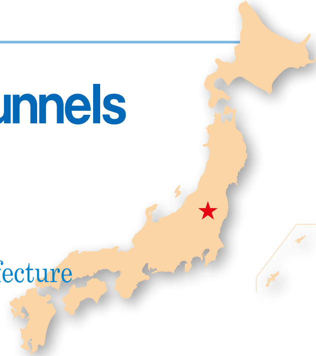
Fig. 2 Data handed off to maintenance management

4. Summary

This issue reported on some of the efforts being undertaken with the construction at Kawanishi. In the future, we will continue to make full use of ICT technology in all processes from surveying to maintenance management, and work together with the client and the contractor to improve productivity.

Countermeasures against swelling of in-service tunnels using precast inverts

— Kashi Tunnel, National Highway No.289 —



Masahiro WATANABE ▶ Chief examiner, Hobara Civil Engineering Office, Fukushima Prefecture
Hirokazu YOSHIDA ▶ Director, Shirakawa Branch, Fujita Construction Industry Co., LTD.
Keiichi OTA ▶ Cheif Researcher, Research and Development Center, Nippon Koei Co., LTD.

1. Introduction

The Kashi Tunnel is a 4,345 m long tunnel that was opened in September 2008.
In addition to overcoming the severe conditions of having only 9 hours during the night for operations before lifting restrictions in the morning, the tunnel is an in-service tunnel on an major road connecting two cities that plays an important role in the local economy, and the impact on road users must be taken into consideration. The tunnel inverts were reconstructed in consideration of the impact on road users.

2. Construction of precast inverts

In selecting the construction method for the reconstruction of the tunnel invert, the precast invert construction method was adopted in consideration of construction costs and economic losses during construction. (Photo 1)
This construction work was carried out during weekday nighttime traffic closures to avoid heavy traffic hours.
The construction procedure consisted of excavation, demolition of the existing invert, and base leveling in preparation for the installation of the precast invert. The nighttime closure began at 21:00, a rough terrain crane was set inside the tunnel, and the precast inverts were picked up from the transporter and installed. Each precast invert has a length of 0.5m in the longitudinal direction of the tunnel. In this project, four precast inverts were installed in one night, totaling 2m in length. The tunnel was then backfilled, etc., and the traffic restrictions were lifted at 6:00 a.m. the next morning.
This process was repeated for approximately 90m of the construction section, and the inverts were reconstructed.
Various measurements were taken in the tunnel for safety management. As a result of the measurements, the settlement of the tunnel arch and displacement of the inner space due to the demolition of the existing invert were observed, but the fluctuations were within the expected values at all locations. In addition, data was obtained that indicated the effects of the invert reconstruction.

Photo 1 Construction scene

3. Results of precast inverts and future challenges

The precast inverts made it possible to construct high-quality inverts.
In addition, productivity of in-tunnel construction was improved by saving labor for concrete casting and curing. Furthermore, construction could be carried out by closing the tunnel to traffic during weekday and night hours, when traffic volume is extremely low, greatly reducing social losses, including the economic impact of the construction.
Future issues include shortening the construction period and reducing road closure time by increasing the amount of precast inverts installed per day.
In addition, we plan to continue observing displacements and stresses in the tunnel after the precast invert is installed and to verify the future stresses used in the design of this project.

Photo 2 Invert damage status

Breaking Through the Complex Geological Formations along the Median Tectonic Line with 3D Computerized Construction

— San-Ennanshin Expressway, Aokuzuretoge Pilot Tunnel, Ikejima Construction Area —

Ko NAKASAI ▶ SUMITOMO MITSUI CONSTRUCTION, Chubu Branch
Shigeru ISHIKAWA ▶ SUMITOMO MITSUI CONSTRUCTION, Hokkaido Branch
Takaaki KOIDE ▶ SUMITOMO MITSUI CONSTRUCTION, Civil Engineering Technology Department

Overview

The Ikejima section of the Aokuzuretoge pilot tunnel on the San-Ennanshin Expressway is a tunnel with a standard excavation cross section of 5.7m in diameter, a section length of 1,168m (total length: 5,014m), and a maximum overburden of 625m. The location of the tunnel is close to the Median Tectonic Line, which is one of the world's largest faults and runs through Japan for about 1,000 km from eastern Kyushu to the Kanto region (with a separation of about 500 m) (Fig. 1), and has a geology that is complex and difficult to predict in advance. In addition, the tunnel is subject to deformation due to the fragile geology consisting mainly of gouge (fault clay) and fault gravel caused by the intense fault movement of the Median Tectonic Line and the large overburden. In response to these geological conditions, a three-dimensional numerical analysis was performed based on geological information such as the location and size of fault fracture zones and the strength of the ground collected three-dimensionally by a cutting face exploration. Furthermore, a support structure was studied in advance, with early closure and double support construction adopted to ensure tunnel stability.

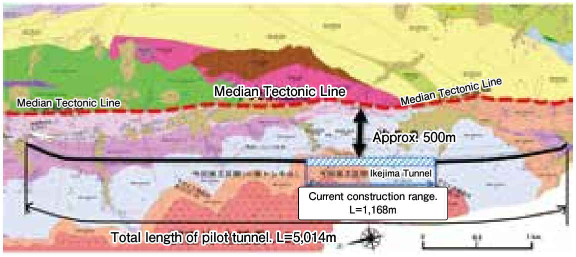


Fig. 1 Geological plane view

1. 3D Computerized Construction

In order to collect three-dimensional information, three types of three-dimensional frontal surveys, namely seismic prospecting reflection survey, electromagnetic resistivity survey, and borehole logging, were carried out in addition to conducting advanced boring surveys on all lines to understand the location of the fault zone in front of the face, geological structure and water retention. Based on the results of these investigations, 3D FEM analysis was carried out to investigate the support structure.

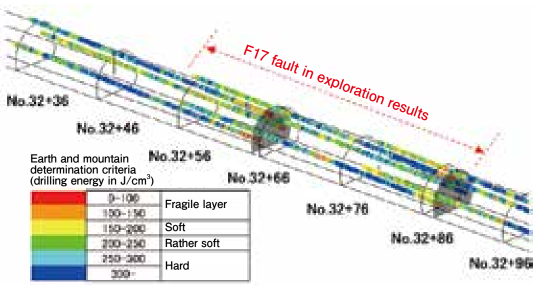


Fig. 2 3D forward survey results

2. Construction of the large overburden fault crush zone

From the results of the three-dimensional frontal survey, it was estimated that there was a fault crush zone where the ground strength was further reduced in the section with the maximum overburden (Fig. 2). Therefore, it was feared that the designed support structure would not ensure the stability of the tunnel, and it was decided to consider the use of a double support structure (Fig. 3) as an even stronger support structure. A 3D FEM analysis was carried out to reflect the detailed three-dimensional geological data obtained from the forward exploration results, the early closure, and the construction steps. As a result, the effect of the double support structure was confirmed to be more than 50% reduction in both the displacement of shotcrete and the stress generated in the main support structure (Fig. 4), and the double support structure was constructed after the test construction.

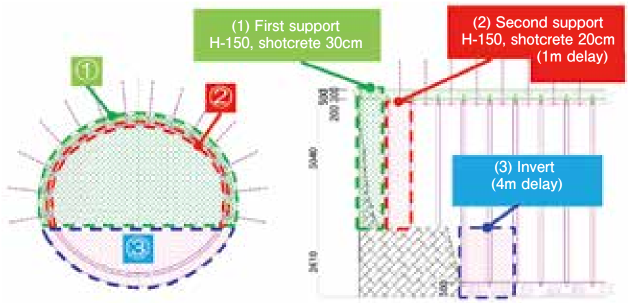


Fig. 3 Structure and construction steps of double support

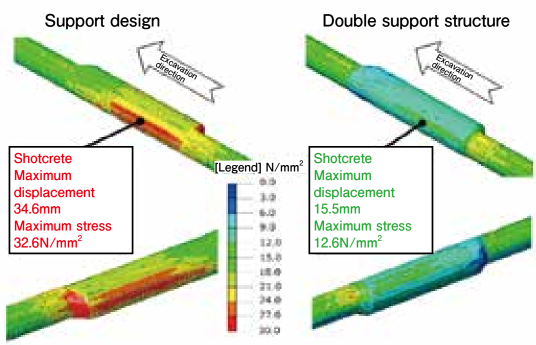


Fig. 4 3D FEM analysis results

The geological conditions along the Median Tectonic Line are far more complex and fragile than assumed at the time of design. For such rapidly changing and difficult-to-predict ground conditions, 3D computerized construction, in which the state and distribution of fault crush zones and fragile layers are grasped by multiple 3D frontal surveys and the support structure is studied by three-dimensional numerical analysis, was an effective means of advanced preparation. We were able to excavate the crush zone section with the maximum overburden without any deformation or excess displacement of the support structure.

Photo Survey point No.37+82 Heavily folded cutting face

Overcoming mountain tunnels under strong ground pressure with a round triple support structure

— Otonaka Tunnel, National Route 40 Otoineppu Bypass —

Katsushi MATSUO ▶ Head of Construction site, Hokkaido Branch, SHIMIZU CORPORATION
Takeshi SHIMADA ▶ Manager, Hokkaido Regional Development Bureau,Asahikawa Development and Construction Department, Shibetsu Road Office

1. Overview

The Otonaka Tunnel (4,686m in length) on the Otoineppu Bypass of National Route 40 is a section of fragile serpentine rock, and was subjected to strong ground pressure rarely seen in tunnels, resulting in deformation near the cutting face and large-scale heaving and destruction of the arch tunnel support (Fig. 1). At the time of the deformation, a closed-ring support pattern with shotcrete t=45 cm and steel support H-200 was adopted, but the section where the deformation occurred was about 450m long, which meant that large-scale re-excavation was unavoidable. During the re-excavation of the deformed section, various surveys, measurements and numerical analyses were conducted to determine the support structure and construction method. A round triple support structure (Fig. 2) was adopted to ensure the stability of the tunne

Fig. 1 Buckling of the arch supports

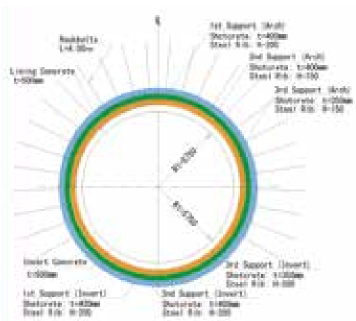


Fig. 2 Triple layered support pattern

2. Deformed section designs

Our view on the support structure of the re-excavation of the section with large-scale deformations is as follows.
The cross-sectional shape of the support structure is circular to ensure stability against strong ground pressure from all sides and unsymmetrical pressure under the heterogeneous ground. The required bearing capacity of the support structure was determined to be the maximum overburden of the serpentine section. The bearing capacity of the support structure was designed to ensure stability against the time-dependent increase in displacement and stress (back-loading) characteristic of serpentine. In order to construct the circular support structure as soon as possible, the cross-sectional closure of the support material was carried out as close as possible to the face. In order to shorten the release time of the face, the maximum thickness of the material that can be constructed at any given time was limited to 50cm.
The deformation modulus of serpentine was set to 150 MPa, the internal friction angle to 10° , and the cohesion to 60 kPa, based on the inverse analysis of the measurement data during the initial excavation and the ground sample test, and the required bearing capacity was determined by numerical analysis. In addition, the maximum incremental stress value assumed after 100 years was set as a time-dependent after-load by analyzing the measurement data during the initial excavation. As a result, a support pattern was designed to construct a round triple support structure (shotcrete 40 cm + 40 cm + 35 cm, steel support H-200 x 3) immediately after excavation (Fig. 2, Fig. 3).

Fig. 3 Ring closing near the tunnel face by triple layered Supports

3. Results of re-excavating the deformed section

Re-excavating the deformed section confirmed that the displacement of the upper half-horizontal inner space remained in the range of -60mm to -80mm and showed a gradual convergence trend after the section was closed. The estimated earth pressures acting on the support structure was slightly lower during the re-excavation than during the initial excavation, but generally increased with the overburden height during both the initial excavation and re-excavation, with the maximum earth pressure estimated to be equivalent to about 140m of overburden.

Triple Layered Tunnel Supports System against Extremely High Squeezing Ground Condition

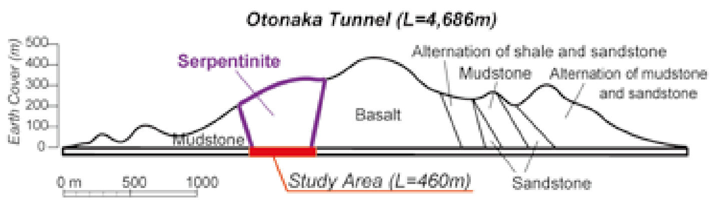


Fig. 1 Geological Profiles in the Otonaka Tunnel

ICT construction of a mountain tunnel that obtained Collaborative Safety 2.0 certification

Hiroyuki HIRANO ▸ Head of Construction site
SHIMIZU CORPORATION, Kyusyu Branch, Civil Department
Takimurozaka Tunnel East Construction Site

Introduction

Humans and heavy machinery work together in a limited space during the construction of mountain tunnels, and there is a high risk of accidents involving contact with heavy machinery, which can directly lead to serious accidents once they occur. To reduce this risk, rules for people approaching heavy equipment have been established at the site, and safety training is provided to ensure that everyone is aware of them. Thus, this does not address human error, and the eradication of accidents involving contact with heavy machinery has not yet been achieved. Therefore, in order to prevent accidents involving contact with heavy machinery during tunneling, we introduced a risk reduction system for contact involving heavy machinery based on Safety 2.0 (ICT-based cooperative safety between humans and heavy machinery) to a mountain tunnel site and obtained the cooperative safety certification.

1. Outline of the site where the cooperative safety certification was obtained

The Takimurozaka Tunnel, located in Kumamoto Prefecture, is a road tunnel with a main shaft length of 4,834m and an evacuation shaft length of 4,898m. This section of the tunnel consists of the 2,679m main shaft on the west side and the 3,069m evacuation shaft. A risk reduction system for contact involving heavy machinery was introduced in the excavation of the main shaft (excavation cross-sectional area: 107m^2).

2. Risk reduction system for contact involving heavy machinery

(1) Human-heavy machine mutual recognition system
In order for people and heavy machinery to work together, it is necessary for the heavy machinery operator to be able to detect the approach of people and for people to be able to detect the approach of heavy machinery. Therefore, AI cameras that recognize people were installed at the rear and sides of heavy machinery, and a device (monitor and alarm lamp) was installed to detect the entry of people into the blind spot of heavy machinery and notify the operator (Fig.1). In addition, sequential lights were installed on the rear of crawler-type heavy equipment such as backhoes, and red LED running lights were installed on the front and rear of tire-type heavy equipment such as wheel loaders, in order to visually inform workers near the heavy equipment of its movement (Photo-1).
(2) Location information management warning system
In order to thoroughly enforce the prohibition of entry during removal work, we developed a location information management warning system that issues an alarm when a person enters an off-limits area. In this system, a transmitter (EXtx tag) is attached to the helmet of a worker, and a receiver (EXBeacon) is installed at the boundary of the off-limits area to manage the location information of the person (Photo-2). The system will sound an alarm when a person enters an off-limits area and notify the heavy machinery operator.
In addition to a loudspeaker, red LED face illumination was installed as a method of quickly and clearly communicating the alarm to all workers even in situations where voices are drowned out or visibility is poor. When an alarm is issued, the area around the face is illuminated in red with a loud warning sound (Fig.2). This allows heavy machinery operators to recognize that a person has entered the face work area or that a heavy equipment operator has disembarked.

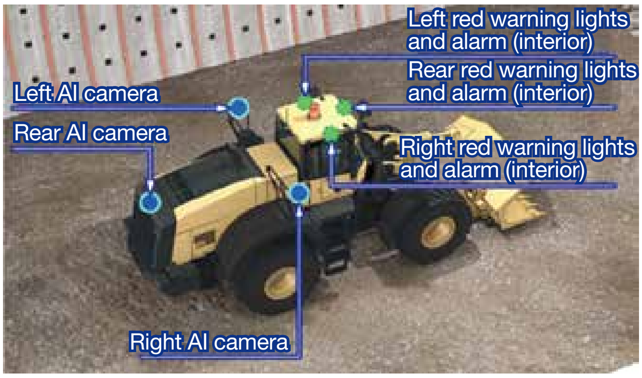


Fig. 1 Human-heavy machine mutual recognition system

Photo 1 Left: Sequential lights. Right: Red LED running lights

Photo 2 Left: Transmitter (EXtx tag). Right: Receiver (EXBeacon)

Fig. 2 Location information management warning system

Excavation of Phase II Tunnel by Early Cross-Sectional Closure at Distance of 0.85m from In-Service Tunnel

Soichiro SATO, Kazuhiro KATAYAMA
▶ West Nippon Expressway Co., Ltd. Kansai Branch, Fukuchiyama Expressway Office Ooi Kohama Construction Area
Shinsuke TAKAYAMA, Hiroshi SAKAI
▶ Asunaro Aoki Construction Co., Ltd.

Introduction

Kisaichi Maruyama Tunnel, an expressway tunnel, started the service in 1993 with temporary two-lane traffic. In 2019, the Phase II tunnel for 4-lane expansion will be constructed over the 125m of entire line very close to the Phase I tunnel in service at a distance of 0.85m. Furthermore, the overburden of the tunnel is less than 1.5 times the width of the excavation, and Kisaichi Maruyama Burial Mound, a national historic site, is located near the ground surface. (Photo 1, Fig.1, Fig.2)

Photo 1 Kisaichi Maruyama Tunnel

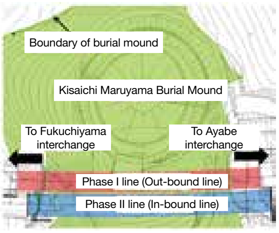


Fig. 1 Plan drawing of Kisaichi Maruyama Tunnel

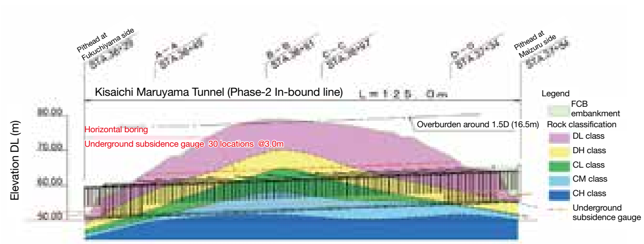


Fig. 2 Geological Profile

1. Construction method

For the Phase II tunnel, we early closed the tunnel with 8m of closing distance by using full-section excavation with an auxiliary bench in order to suppress the deformation. We selected the support of DIII pattern for the entire line (Fig. 3). We applied all ground fastening method along the entire line to prevent collapse. The steel pipe was ϕ 114.3mm, t=6mm, L=12.5m, and the setting range was 120°. A double arrangement with a shift length of 5m was used at the entrance, and a single arrangement with a shift length of 9m was used at the central part of the tunnel.

For the gap of 0.8m between Phase I and Phase II tunnels, injection type fore polling was placed in and improved with urethane-based injection material to prevent collapse during excavation (Fig. 3).

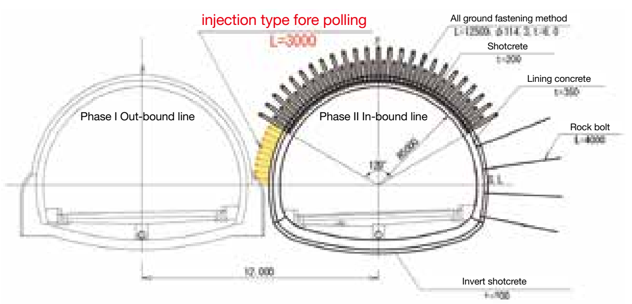


Fig. 3 Support pattern for Phase II line

2. Measurement control

We installed horizontal inclinometers in the horizontal boreholes at the top of Phase II line at 3m intervals to measure the amount of subsidence at the top in real time before passing through the face. (Fig.4)

We set the control standard value for the subsidence as 30 mm, which is obtained by FEM analysis when the increased tensile stress of the Phase I line reaches the allowable value (1,080kN/m^2, which is 6% of the design standard strength). In addition, we created a characteristic curve of the control standard value according to the distance from the measurement point to the face in order to predict the final displacement of the measurement point before it converged. Based on the data we took early countermeasures according to each control level. The shape of the characteristic curve was calculated by three-dimensional FEM analysis. We set the curve so that subsidence starts at the location of 30m in front of the face, converges to 17mm when passing the face, and converges to a final settlement of 30mm after the face passed 30m.

3. Construction result

Although the ground subsidence started at a location closer to the face than predicted, the final subsidence amount was almost consistent with the predicted analysis value. Since the subsidence amount before convergence was also below the control level of the characteristic curve, additional countermeasure or traffic restrictions of Phase I tunnel was not required. (Fig. 4).

The method of early closure by full-section excavation using all ground fastening successfully suppressed the displacement of the tunnel and reduced the impact on the Phase I tunnel to ensure the soundness of the tunnel. We concluded that our approach was an appropriate construction method for the adjacent construction of tunnels in service.

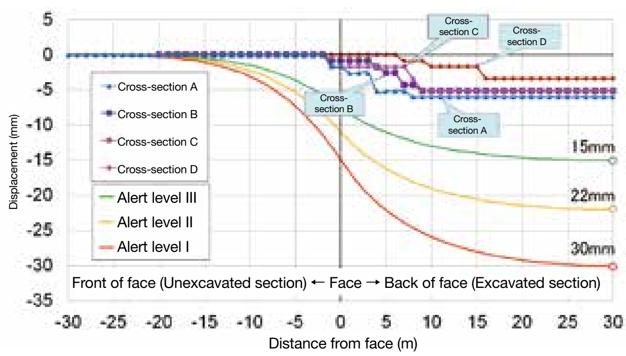


Fig. 4 Result of Ground Subsidence

Large-Section Shield Tunnel Excavated Directly Beneath Runway in Service
Tokyo International Airport Tunnel

Seiji JINBO ▶ Construction Manager, Tokyo Civil Engineering Branch, SHIMIZU CORPORATION
Ryunosuke KASHIMA ▶ Design Manager, Civil Engineering Technology Division, SHIMIZU CORPORATION

1. Introduction

This project involved constructing a road tunnel that can be used by large buses using a shield tunneling method in order to improve the convenience and punctuality of connections between international and domestic flights at Tokyo International Airport. The outer diameter of the shield tunnel was about 12m, and a mud shield was used. The shield tunnel passed directly under airport facilities such as runways, taxiways, aprons, monorails, and highways in service in the heterogeneous and extremely soft ground of the reclaimed land, so one of the most important issues in this project was to minimize the impact on these critical structures. Fig. 1 shows a bird's-eye view of the tunnel.

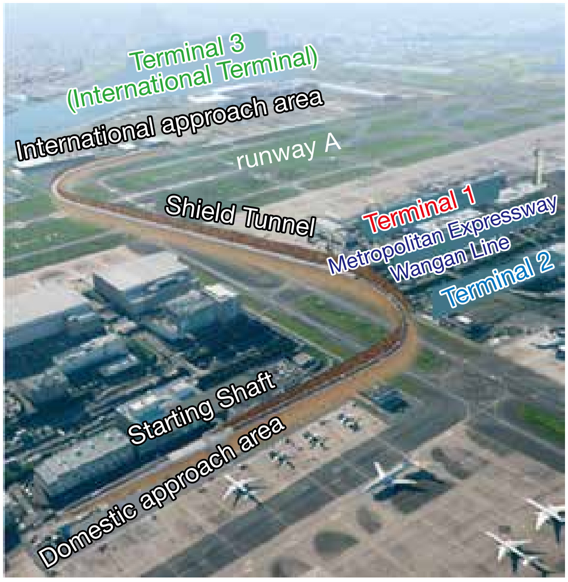


Fig. 1 Bird's eye view (image)

2. Measurement and Control of the Ground and Critical Structures in the Construction Area

Fig. 2 shows the ground in the construction area and the longitudinal alignment of the tunnel. The ground is very soft, with the upper sand layer (As1 layer) dredged and filled with sludge (Ac1 layer) and construction soil (Bs layer) dredged from the navigation channel in Tokyo Bay. In addition, the excavation cross section has obstructions such as drainage material used during ground improvement and steel pipe piles left over from the construction of the Tokyo International Airport Offshore Development Project.

The volume of deformation was measured by level surveying during the night when the airport facilities were closed, and by ground-mounted synthetic aperture radar to determine the deformation trend when the airport was inaccessible. The ground-mounted radar was used to determine subsidence trends because the radar has a small angle of incidence and low reflection intensity, which results in large variations in measurement accuracy. In addition, the excavation data was monitored in a central control room to manage the deformation in a comprehensive manner.

In order to instantly detect deformations that exceed the permissible values, measurement methods such as dynamic observation using a non-prismatic total station and road surface monitoring using a high-sensitivity telephoto camera were used in combination within the influence zone of Runway A. Measurement management was conducted 24 hours a day, 7 days a week.

As a result of these measurements, the construction work was completed with the maximum settlement of 11 mm, which was lower than the primary control value (12 mm).

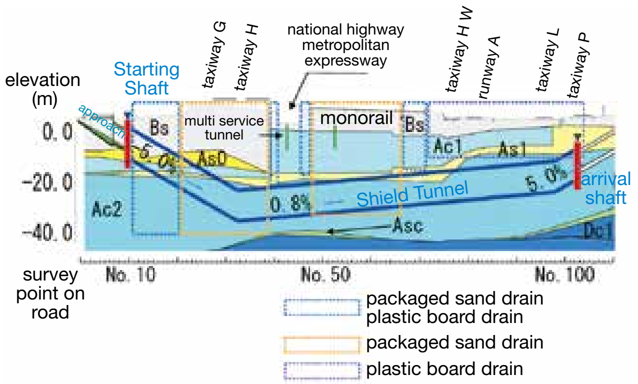


Fig. 2 Longitudinal image

3. Summary

In this project, it was necessary to control ground deformation caused by shield tunneling because the shield tunnel had to pass directly under critical structures such as the runway, which was in service. Various deformation measurement methods were used to monitor deformation in real time during shield tunneling. As a result, the shield tunneling was carried out without causing any problems with aircraft operations.

Photo 1 Domestic flight approach area (at starting shaft)

Construction of a Large-Scale Composite Box Culvert Encompassing a Complex System of Intertwining Ramps

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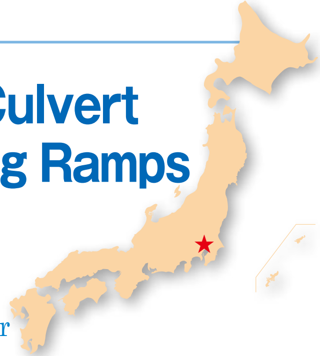
Wataru OGAWA ► Ministry of Land, Infrastructure, Transport and Tourism Kanto Regional Development Bureau Tokyo Outer Ring National Highway Office Deputy Director

Takayuki SATO ► Ministry of Land, Infrastructure, Transport and Tourism Kanto Regional Development Bureau Tokyo Outer Ring National Highway Office Engineering Division



Introduction

The Tokyo Gaikan Expressway is an 85-km-long automobile-road that connects a 15-km radius of central Tokyo in a circular direction and serves to disperse traffic concentrated in the city center by interconnecting inter-regional trunk roads in radial directions.
The construction work for a part of the Chuo JCT, which connects the Chuo Expressway, the Gaikan Expressway, and the Tokyo Metropolitan Expressway, and where seven ramps are concentrated, was carried out under a design-build, lump-sum order system. This paper introduces the features of the composite box culvert structure proposed by the contractor (Fig. 1), which combines the large-scale open-cut method and the pneumatic caisson method, and the status of the construction work.

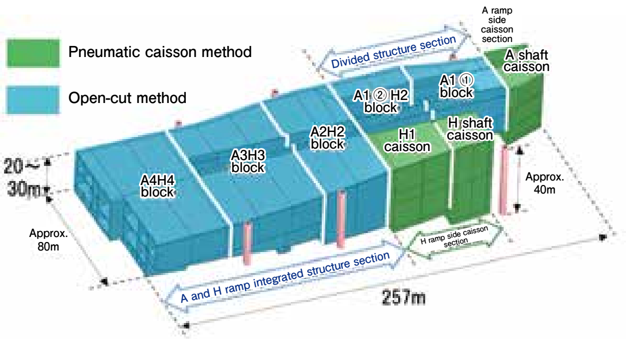


Fig. 1 Overall view of composite box culvert structure

1. Main body structure rationalization

When constructing a structure with only the space required for the road, the shapes of the sidewalls and top slabs change in a complicated manner, making it necessary to increase the thickness of the material and the amount of reinforcement at the corners where stress is concentrated, which poses a risk to the quality of the concrete, due to temperature cracks and poor filling. In this project, a composite box culvert structure was adopted (Fig. 2) to share the vertical load with the axial force of the structural wall and reduce the overburden pressure due to the reduction of the backfilled soil volume (soil volume reduced by about 80%), thereby eliminating the overcrowded reinforcing bars at the corner (reinforcing bar volume reduced by about 20%) and reducing the thickness of the material, resulting in a slimmer structure. (Fig. 3)

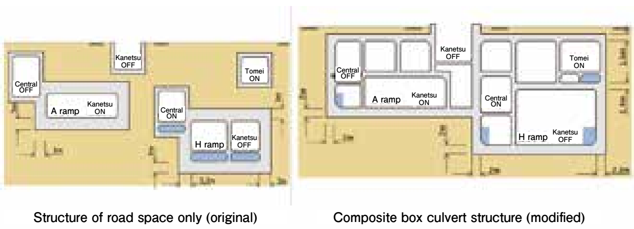


Fig. 2 Changes in the main structure

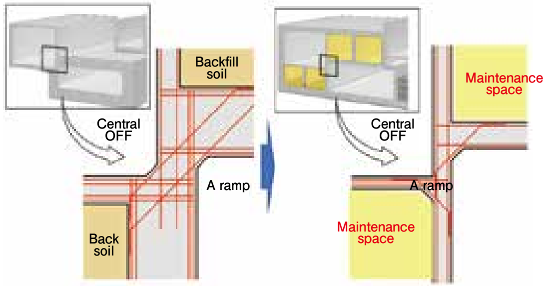


Fig. 3 Streamlining of the structure

2. Temporary structure and construction rationalization

Since the work site is small compared to the construction area, a full lining structure (A=15,000 m2, Fig. 4) was adopted. By fixing the ends of the girders to the earth retaining wall, the horizontal force acting on the end-supported piles of the lining was reduced and reinforcing materials such as diagonal materials were omitted to rationalize the temporary structure. As a result, a large space was secured above the ground and inside the shaft (Fig. 5), creating an easy and safe work environment and reducing the amount of temporary steel used by about 10%.

Fig.4 Securing the work area through full lining

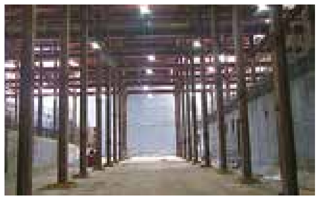


Fig.5 Rationalization of temporary structures

3. Use of ICT technology to ensure quality and improve management accuracy

Information for each transport vehicle with an agitator, including the time from concrete mixing to the completion of concrete placement and the location of concrete placement, was integrated into a 3D model. This improved the efficiency of concrete lay-up time management, material and construction history information management, and contributed to quality assurance by reducing the occurrence of cold joints and shortening the working hours for quality control work. (Fig. 6)

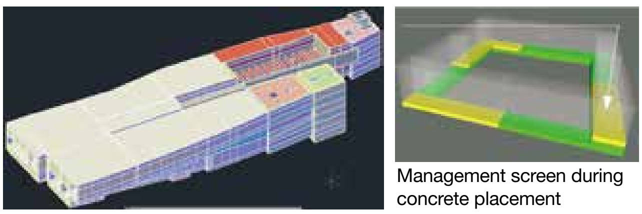
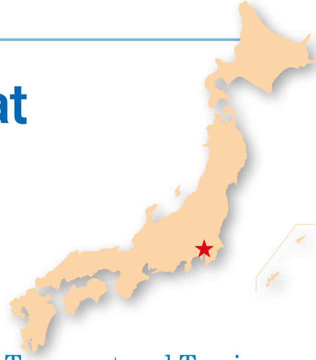


Fig.6 Concrete placement management system

Immersed tunnel in the Tokyo coastal area that shortened the construction period Uminomori Tunnel in Tokyo Port



Osamu IEJIMA ▶ Manager, Tokyo Port Office Development Section1,
Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism.

1. Project Overview

The Tokyo Port Uminomori Tunnel, which has been in service since June 2020, is located in the coastal area of Tokyo. The port of Tokyo is an important logistics hub that supports the lives and industrial activities of eastern Japan as well as the Tokyo Metropolitan Area. In order to ensure such smooth logistics at the Tokyo Port, this tunnel was constructed to eliminate the chronic traffic congestion on the surrounding main route. Of the 2.5km long tunnel, a 931m undersea tunnel that crosses the route was constructed by the immersed tunnel method. The immersed tunnel consists of seven submerged boxes with a length of 134m, a width of 27.8m, and a height of 8.35m. Table 1 shows the construction companies of the tunnel element.

2. The Biggest Challenge in Tunnel Construction

Looking at the results of the immersed construction method in Japan, the construction period of a submerged tunnel of the same scale as the Uminomori Tunnel is usually 8 to 10 years. The Uminomori Tunnel, the 29th case under the Japanese immersed construction method, was launched after the IOC General Assembly in September 2013, which decided Tokyo as the site for 2020 Olympic and Paralympic Games. Since the competition venues and the Olympic Village of the Tokyo 2020 Games were concentrated in the waterfront area of Tokyo, the tunnel was expected a great role as a transportation route for the people involved in the Games.

3. Ingenuities Implemented by the immersed Construction Method

In order to significantly shorten the construction period, the ingenuities that were implemented by the immersed tunnel method are shown below. First, from the viewpoint of domestic construction results and securing routes for general vessels, it had been initially planned as eight tunnel elements for the undersea tunnel. However, as a result of additional reviews it was modified to seven elements with a length of 134 m, which is the longest in Japan, to shorten the process by reducing the number of immersion elements. Next, for the structure of the tunnel elements, we adopted the full sandwich type steel-concrete composite structure that is often seen in recent immersed tunnels in Japan, where there are many earthquakes.
The steel shells were divided and manufactured at more than 10 factories nationwide, and then assembled at two shipyards in Tokyo Bay by sea transportation (Photo 1). The completed steel shell was moored on the quiet quay of Tokyo Bay, and then high-fluidity concrete was placed inside the steel shell. The completed tunnel element had been immersed on the seabed of Tokyo Port and safely stored until it was sunk into the seabed. Thanks to this manufacturing method, a huge immersion box was smoothly supplied to the waterfront area of Tokyo.

These seven submerged boxes were sunk in succession in a short period of 11 months (Photo 2). The process was shortened by another 3 months compared to the conventional method thanks to the key element method which omits the final joint as the fourth case in Japan (Fig. 1).

Table.1 Constituent Company of the joint venture

Tunnel element No.	Constituent company of the joint venture that was constructed
1	KAJIMA CORPORATION TOA CORPORATION Aomi Construction Co., Ltd.
2, 3	TOA CORPORATION KAJIMA CORPORATION WAKACIKU CONSTRUCTION CO.,LTD.
4, 5, 6	PENTA-OCEAN CONSTRUCTION CO.,LTD. TOYO CONSTRUCTION CO.,LTD. NIPPON STEEL ENGINEERING CO., LTD.
7	Taisei Corporation PENTA-OCEAN CONSTRUCTION CO.,LTD. DAIHO CORPORATION

Photo 1 Steel shell of Tunnel element

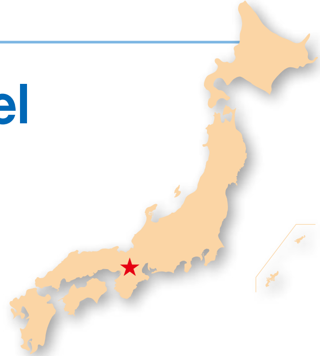
Photo 2 Immersion status

Fig. 1 Schematic diagram of the key element construction method

Underground connection to the existing tunnel using a slide hood

— Public Sewerage District No. 10 Pipe Construction Work in FY2016 —

Masao YONEKAWA ▸ HIGASHIOSAKA CITY
Hiroyuki HIGASHINO ▸ OBAYASHI CORPORATION



Introduction

The site was located in a flat area where rainwater did not flow easily into rivers, causing frequent flooding. Therefore, a rainwater drainage countermeasure project is underway to create a safer town to live in. As a part of the project, this work involves the construction of a 610-meter-long rainwater augmentation tunnel using the EPB shield method. In this construction, the arrival method using a slide hood was adopted as a safe and reliable method for the lateral underground connection to the existing tunnel in operation.

Fig. 1 Site location

1. Characteristics of this construction

This project involves the underground connection to the side of an existing tunnel (I.D.4.75m), which was constructed in previous years. At the connection, a primary lining with steel segments for opening and a secondary lining with a thickness of 425mm is constructed. The overburden at the connection is about 14m, the water level is about GL-2m, and the soil is diluvial clay with N value of about 10 and diluvial sandy soil with a N value of about 50, with very soft alluvial clay and intervening sand layers directly above.

2. Challenges and solutions

There were no suitable size manholes near the underground connection, which limited the size of materials and equipment that could be brought into the existing tunnel. As a result, it was not possible to install an entrance device or bulkhead to stop the water flow.
In consideration of the balance between safety and cost, TBM equipped with a slide hood was used to make the underground connection (Photo.1). The cutter head is equipped with a telescopic spoke, which can be retracted for the underground connection (Fig.2). The TBM (O.D.3.64m) stopped at a predetermined position about 80 mm before contacting the existing tunnel, and after cutting the primary lining from the existing tunnel side, the built-in slide hood was pushed out 1.2m in length to connect. As a result, the exposure of the ground around the connection was minimized, and the collapse of the ground and the occurrence of water inflow were prevented (Photo.2). In addition to the jet grouting, chemical grouting was additionally carried out at the connection location prior to the extrusion of the slide hood to protect the connection from water inflow, which was strictly controlled at less than 200 cc/min.
With the above measures, the underground connection was completed without any major problems.

Photo 1 EPB TBM

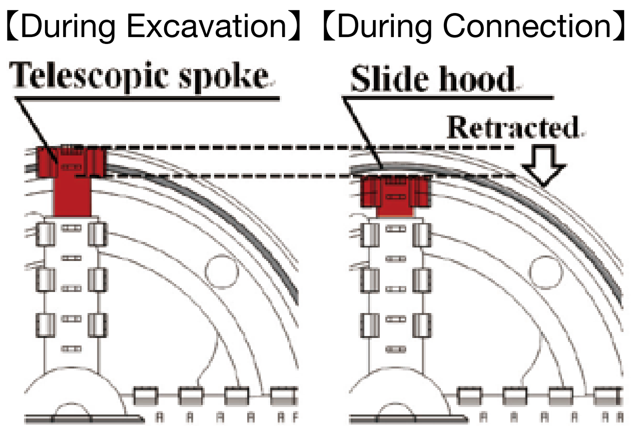


Fig. 2 Telescopic spoke of the cutter

Photo 2 Underground connection complete

22.5% uphill electric cable tunnel by mud-pressure shield in composite ground containing weathered granite

Masaaki YANO ▸ Kumagai Gumi Co., Ltd.

1. Geological overview and investigation

The geology was a very compact sand and gravel layer mixed with cobble stones with a maximum diameter of 3,000 mm up to about 400 m from the start of the tunnel. After that, the granite at 1,100 m was weathered to qu=1MN/m^2 at depths shallower than 20 m. The distribution of faults, etc., was also examined. The distribution of faults was determined using a reflection survey.

2. Cross-section and alignment

The inner diameter of the power cable tunnel was 3,000 mm. The longitudinal alignment was designed to have an approximate elevation difference of 120 m between the start and arrival points, with a gentle slope of less than 5% for 1,100 m, a horizontal section of 50 m, and a steep slope of 22.5% for 350 m (Figure 1). In Japan, there have been only a few shield tunneling projects with a steep slope exceeding 20% for more than 350 m in a row (about 4,300 projects), making this a rare case.

3. Challenges and countermeasures for composite ground

A mud pressure shield was used to tunnel a single shield through composite ground where sediment and bedrock were distributed. A faceplate-type cutter head and roller cutter were equipped to crush the bedrock to less than 300 mm in size and remove boulders (max. Φ 300 mm) from the sand and soil. In addition, a roller cutter was installed in the center of the cutter to cope with the unexpected appearance of hard rock in the bedrock area.

4. Shield equipment for constructing a steep slope of 22.5%

The segments were made of RC segments with smooth inner surfaces. A water-assisted earth moving system was used to discharge the earth from the tunnel (Figure-2). Although a mud treatment plant was required, the majority of the soil was disposed of as general overburden, thus reducing the environmental impact. In order to construct the steep slope of 22.5%, a rack-and-pinion battery car, a runaway prevention device, an automatic horizontal segment cart, and an electric segment feeding device were used.

5. Construction results

During excavation of earth and sand, problems such as blockage of the soil drainage pipe occurred due to the appearance of boulders with a maximum diameter of 400 mm, which was larger than expected, but the excavation did not stop for a long period of time and was generally stable. During the excavation of bedrock on a gentle slope, the thrust tended to be high, but this was overcome by increasing the injection rate of an additive material (polymeric coagulant). In the steep-gradient section, granite that had been subjected to strong winds formed gravels, which lodged in the pump empennage and interfered with pump rotation. The pumps were able to reach the same speed (average 153 m/month) in the steep section as in the other sections, and the overall process took about 10 months (average 143 m/month) for a distance of 1.5 km, as originally planned (Photo-1).

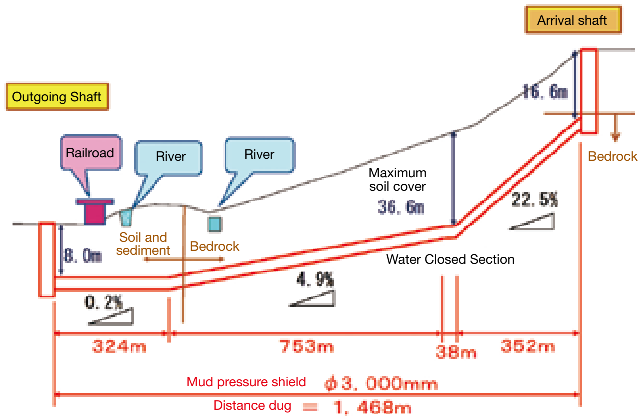


Fig. 1 Shield longitudinal alignment

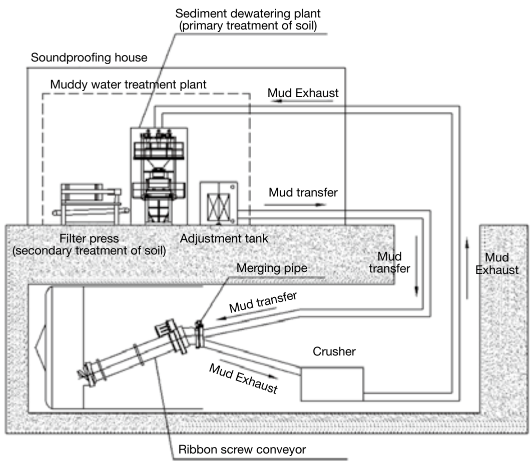


Fig. 2 Image of water-assisted earth moving system

Photo 1 Arrival status

The construction of a long-distance deep shield passing through central Tokyo

— Chiyoda Trunk Line, Tokyo sewerage —

Takumi IRIDE ▸ Tokyo Metropolitan Government, Bureau of Sewerage, 2nd Core Facilities Reconstruction Office, 2nd Construction Division Director

Hidenori YOSHIDA ▸ Okumura-Daiho Corporation joint venture (special) Chiyoda Trunk Line Construction Office

Overview

The purpose of this project is to construct a new sewerage trunk line (ϕ 4900mm) to reconstruct the aging existing sewerage trunk line and to reduce the amount of sewage discharged from the combined sewerage system into rivers during rainy weather. The construction method involves the use of a slurry shield. A distance measuring around 8.7km from the start to the end will constitute one span. The shield tunnel will be constructed at a maximum depth of 60m because it will traverse under the city center where buried pipes and subway structures are congested.

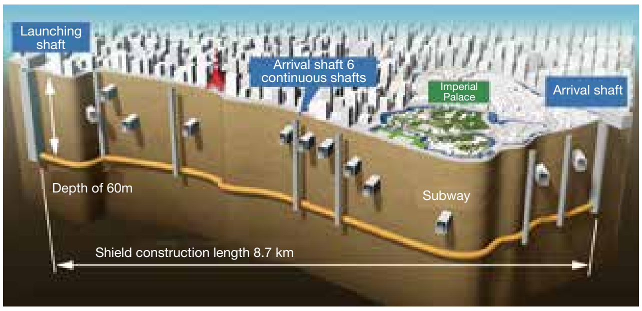


Fig. 1 Shield route map

The ground on which the shield tunnel passes is Diluvium, and the groundwater level is high at about GL-2.0m. At the initial stage of excavation, the soil is composed of consolidated silt and fine sand, which then transitions to sandy silt.
At the later stage of excavation, the soil becomes mainly consolidated silt, which is extremely hard with an N value of over 50.

1. Construction challenges and countermeasures

There are three main challenges that must be addressed in the construction of this project: improving the durability of the shield machine for the long-distance construction (approximately 8.7 km), countermeasures against high water pressure for the shield machine for excavating at deep depths (approximately GL-60m), and process control for long-distance construction.

1-1 Improvement of Shield Machine Durability in Long-Distance Construction (approximately 8.7km)

Improving the durability of the shield machine is crucial, given the long distance (approximately 8.7km) of one span for this construction. As a countermeasure, a mechanical bit change executed by the slide cutter method was used. This refers to pushing out the rear bit when the leading bit is worn out to allow digging to continue. This method improves the durability of the shield tunneling machine and eliminates the need for bit replacement, making it possible to engage in construction over a long distance of approximately 8.7 km.

1-2 Measures against high water pressure for shield machines excavating in deep areas (approximately GL-60m).

The longitudinal alignment of the shield tunnel is at a great depth with an average overburden of about 50m and a maximum overburden of about 60m, and the tunnel is constructed under high water pressure. Therefore, two measures were taken to improve and maintain the water sealing performance. The first measure is the three-stage arrangement of tail brushes, which reduces the risk of water leakage and improves the water sealing performance compared to the two-stage arrangement. The second involves installing an emergency water stopper. An emergency water stopper is installed between the second and third layers of tail brushes so that the first and second layer tail brushes can be replaced during excavation. When the deterioration of the tail brushes is confirmed, the brushes can be replaced to ensure the water stopping performance.

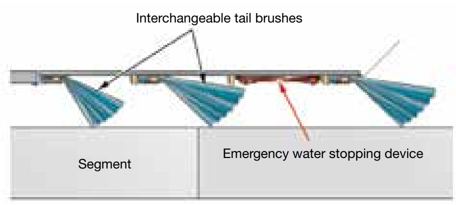


Fig. 2 Three-stage tail brush arrangement

1-3 Process management in long-distance construction

For long-distance shield constructions, the shield tunneling and assembly work accounts for a large proportion of the critical path in the process. Therefore, it is necessary to improve the efficiency of the work in order to avoid the risk of extending the construction period and also to reduce the cost. In this project, the number of assembly operations was reduced by widening the segment width from the standard 1.2m to 1.5m, and the digging cycle time was shortened by adopting a segment (honeycomb segment) that enables simultaneous digging and assembly operations.

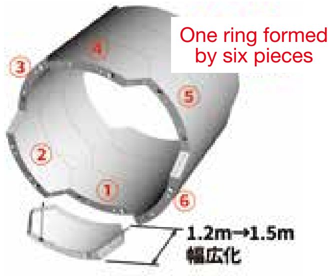


Fig. 3 Honeycomb segmen

Photo 1 Shaft photograph

2. Contact

Tokyo Metropolitan Government Bureau of Sewerage Official Website http://www.chiyodakansen-gesui.tokyo.jp/
Okumura-Daiho Corporation joint venture (special) Chiyoda Trunk Line Construction Office
TEL: 03-6272-3803 FAX: 03-3556-8036

Trial Inspection of Finished Dimension by 3D Laser Scanner

Jun KUBOTA ► West Nippon Expressway Company Limited Kansai Branch Wakayama Construction Office
Shinya YAMANAKA ► West Nippon Expressway Company Limited Head Office Construction Department Construction Division
Sho YAMAMOTO ► SHIMIZU CORPORATION, Kansai branch
(*Futoshi KUSUMOTO* ► SHIMIZU CORPORATION, Underground Section)

Trial inspection of mountain tunnels includes measurements of the cutting face, excavation surface, and tunnel support structure from the cutting face, and the lining behind the cutting face. The former is to confirm the margin of construction and the thickness of shotcrete at the cutting face, excavation surface, and shotcrete surface. The latter is to confirm the thickness of the bore displacement of the tunnel and lining thickness. We tried using a 3D laser scanner to digitally inspect the finished dimension of Kawabe Daini Tunnel in Wakayama prefecture, and these are our findings.

1. Digital System to Inspect Finished Dimension

The digital inspection system of the finished dimension consists of Pet'sS, which surveys the face of the construction cycle using a laser scanner and processes, analyzes, and displays color-coded point cloud data, and Pet'sL, which surveys the BL unit of the lining behind the face and processes and color-codes the point cloud data. The configuration of the system is shown in Figure 1.

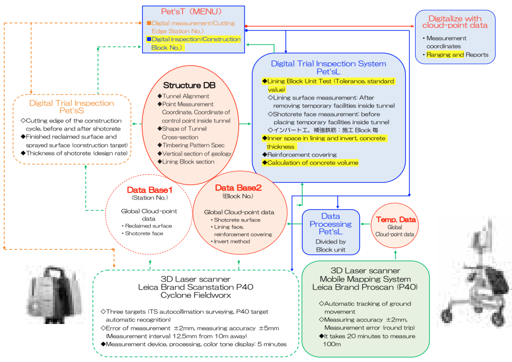


Fig. 1 Digital Final Dimension Inspection System

2. Inspection of the Final Dimension

The digital inspections of the final dimension of the construction cycle of the cutting face was basically to be performed twice, before and after the shotcrete was applied. The point cloud data was color-coded on a PC screen after inspecting the excavation surface, shotcrete surface, and thickness of the shotcrete. The bore displacement of the tunnel was inspected in BL units. Inspection was done with the point cloud data displayed in color. The color tone display of the bore displacement of the tunnel is shown in Figure 2. As a result of the above inspection, it was confirmed that the difference from the target values for the excavation surface, face, and shotcrete surface during the construction cycle is displayed in color in real time, enabling quantitative and efficient confirmation of the final dimension. In addition, it was confirmed that the point cloud data stored in the data base in global survey coordinates can be color-coded and displayed on the PC screen for measurement in the bore displacement of the tunnel.

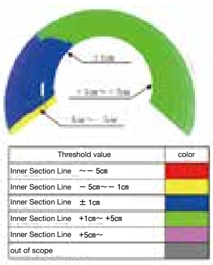


Fig. 2 Color-coded Display of Bore Displacement of Tunnel

3. Conclusion

This method not only enables real-time visualization, quantification, and reproduction of the final dimension of tunnels, but also has the advantage of significantly reducing the time required for inspection, especially in the case of long tunnels. We plan to continue to apply this method, conduct trials, identify issues, improve it, and develop it into a final dimension inspection technology for mountain tunnels.

Inspection of Tunnels Using a Running Vehicle with Tunnel Lining Surface Imaging Technology

Akio KAMITANI ► Nippon Expressway Research Institute Company Limited
Research Engineer (P.E.jp)

1. Current Status of Tunnel Inspection

Road tunnels in Japan are required by law to be inspected visually every five years. Japanese expressway companies, which own and maintain many tunnels with a total length of approximately 1,800 km, are using vehicles with tunnel lining surface imaging technology to carry out inspections efficiently and with high accuracy. (Photo 1)

Photo 1 Taking images of the lining surface

2. Features of Lining Surface Image Capturing Technology

The surface image of the lining obtained by this technology is extremely accurate and can capture surface deformations such as cracks and water leakage with the same accuracy as close visual inspection.

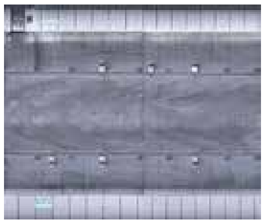


Photo 2 Surface image of the lining

In addition, the use of elevated work vehicles for close visual inspection usually requires traffic control on highways, which sometimes causes traffic jams. This causes considerable significant social impact. (Photo-3) However, the image capturing vehicle in this technology can acquire images of the lining while traveling at 80 km/h without any need for traffic control.

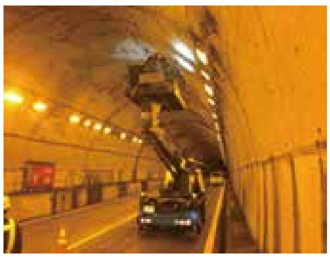


Photo 3 Inspection by close visual inspection

3. Details of Inspection Method

All tunnels are inspected once every five years, and images of the lining surface are taken. The presence or absence of deformation is then checked at the office. The scale of crack occurrence is automatically calculated using specialized software. Engineers will conduct close visual inspections onsite only in areas where deformations have become apparent. In this way, efficient and highly accurate inspections are realized, and safe and comfortable expressway services are provided.

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Tunnel Disaster Prevention Facilities in Tokyo Metropolitan Expressway

Kazuhito UCHIUMI ► Deputy Manager, Engineering Research & Development Division, Engineering Department, Metropolitan Expressway Company Limited

The Metropolitan Expressway is an urban expressway in the Tokyo metropolitan area. The expressway is 327.2km long and carries one million vehicles per day. It is one of the major arteries in the area. Yamate tunnel, of which the last section opened in 2015, is the world's longest expressway tunnel with a length of 18.2km. The tunnel is equipped with cutting edge technology to prevent tunnel disasters. This paper will introduce the traffic operation facilities among the six tunnel disaster prevention principles (operating emergency facilities, traffic operation, collaboration with relevant parties, PR/enlightenment, installing emergency facilities, fireproof structures).

1. Detection of Accidents at Early Stages

In addition to emergency telephones, push alert devices, and fire detectors, the Traffic Incident Detection System which uses CCTV images to detect events such as vehicle stoppages and fires at an early stage, is installed and alerts traffic control operators to accidents by flashing lights.

Fig. 1 CCTV image

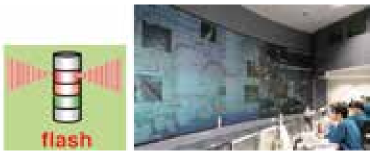

Fig. 2 Traffic control Room

2. Informing drivers

When an accident occurs, warning signs and variable message signboards are used at the entrance of tunnels to warn drivers not to enter. Inside, the system warns drivers to evacuate the tunnel. In addition, loudspeakers equipped with echo cancellation technology encourage drivers to evacuate their vehicles in an easy-to-hear voice.

Fig. 3 Variable Message Signboard

Fig. 4 Echo Cancellation Technology for Loudspeaker

3. Tunnel Closure by Traffic Patrol

In addition to the traffic patrol vehicles, patrol members on motorcycle arrive at the tunnel scene within three minutes to close the tunnel. Warning signs with flashing light at the tunnel entrance will intuitively alert drivers that an accident has happened, and the tunnel is closed.

Fig. 5 Dispatch of motorcycle patrol

Fig. 6 Prompt Tunnel Closure by manual barriers

Reference:
https://www.shutoko.co.jp/en/index/driving/emergency/
https://www.its-jp.org/english/files/2021/11/its2021_shuto_kosoku_210824_x1a.pdf

25

Development of Next Generation Tunnel Construction System: Remote Control Technology for Shotcrete

KUMAGAIGUMI

Background

The work of applying shotcrete inside mountain tunnels has various risks such as exposure to dust or getting involved in the collapse of the tunnel face. This is because workers operate the shotcrete robot near to the face within the narrow tunnel. To improve the working environment and safety, we developed a technology to remotely operate the shotcrete robot in a clean working environment away from the tunnel face.

Outline

The main technology used for the shotcrete robot is the use of multiple network cameras on the erector boom and the main body of the erector-mounted shotcrete sprayer (Photo 1)These are to ensure the operator's field of view. The operator can operate the remote control box of the shotcrete robot while viewing the images taken by the camera on a monitor screen installed in a mobile operation room away from the tunnel face (Photo 2)The network camera is highly waterproof and dustproof, with a dustproof air shower ring around the lens to prevent aggregates and cement particles from attaching.
The remote-control system is a network-compatible system that efficiently transmits video data and operation signals wirelessly (Fig. 1).
The shotcrete robot has an automatic nozzle swing function, which eliminates response reduction caused by the video delay (200~300ms), which is a common issue in remote operation. Also, laser beams come out from the tip of the nozzle to enhance the visibility of the spraying area through the screen and ensure the efficiency of shotcrete application.

Photo 1

Photo 2

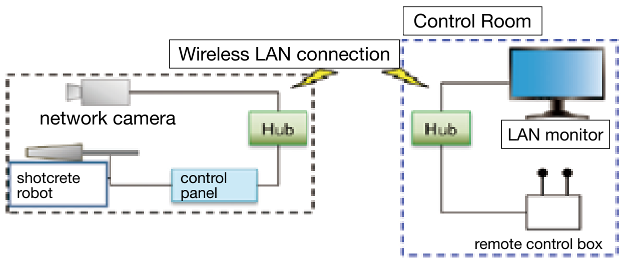

Fig. 1 Shotcrete system

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Remote Control Technology for Applying Shotcrete “T-iROBO™ Remote Shotcreting”

Takenaka and H. Kinoshita ► Taisei Advanced Center of Technology, Taisei Corporation, Tokyo, Japan

During construction of mountain tunnels in Japan, occupational accidents have often occurred due to rocks and shotcrete falling from the face. As workers near the face must work in high dust environment, it has been a challenge to improve the safety of workers and the work environment near to tunnel face. To improve this situation, we developed "T-iROBO Remote Shotcreting," a system that allows spraying work done remotely from the operator's seat of the sprayer using a head-mounted display (HMD).

This technology consists of multiple devices (Fig. 1). The system allows the operator, who is wearing the HMD, to remotely operate the sprayer from the driver's seat by viewing images from multiple cameras. The spraying operator can conduct the spraying work as if the tunnel is nearby by looking at the three-dimensional images of the face via HMD. Moreover, from the images taken by both stereo cameras and HMD, the operator can detect the spraying thickness with high accuracy. The stereo cameras are installed at two locations: the front of the operator's seat, where the operator can have a bird's-eye view of the entire spraying area, and the bottom of the man cage, where the operator can change the position of the camera to check the details of the spraying. Images from these cameras can be easily switched to be shown on the HMD, so the operator can remotely control the machine without any blind spots.

This technology has been used at three mountain tunnel construction sites in Japan, and its safety and effectiveness have been confirmed.

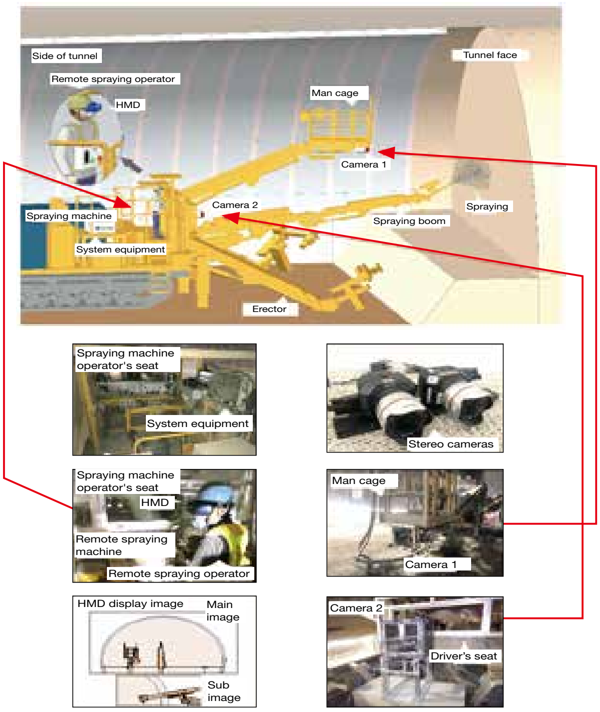

Fig. 1 T-iROBO Remote Shotcreting

27

Shield construction using AI to improve efficiency and quality - "AI Transform Shield

Masami ICHIKAWA ► TODA CORPORATION, Civil Engineering Technology Administration Division, General Manager for ICT/AI Promotion Division (Civil Engineering)

1. Outline

Maintaining the position and posture of the shield machine against the natural ground is important in managing the digging with shield tunneling method. Even though all excavation data is mechanically accumulated, it is difficult for human operators to acknowledge all the data to manage excavation according to the quality of the soil. This technology utilizes artificial intelligence (AI) to measure the posture of the shield machine and uses past digging data to automatically change the posture of the shield machine when going forward.

2. Features

The AI, which accumulates shield tunneling data during and after excavation, searches for past tunneling data that has the most similar composition of the soil during excavation. The AI extracts items such as face pressure, cutter torque, and corresponding jack speed when the shield machine was excavating smoothly in the past cases. Based on the extracted data and the automatic surveying data, the system continuously presents the best jacking pattern that has the smallest deviation from the reference line.

3. Effectiveness

The AI further evolves by learning from a huge amount of teaching data accumulated from the shield tunneling data during and after construction. This helps improve the efficiency and quality of construction.

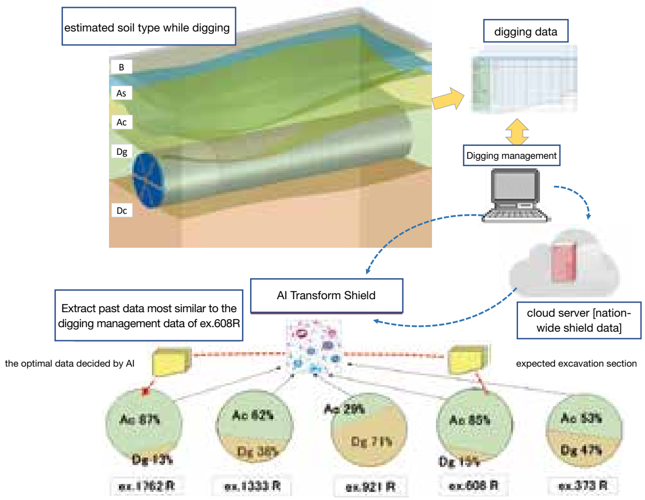

Fig. 1

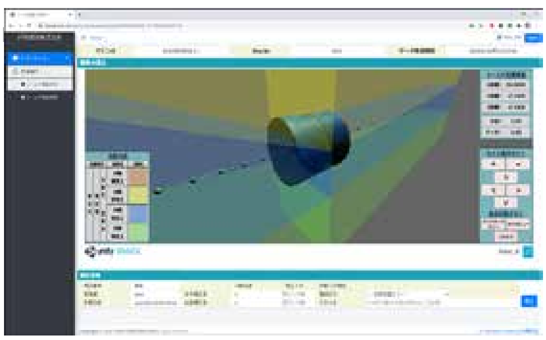

Fig. 2

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Light-Weight Steel Pipe for Forepiling Made with High-Strength Material "AGF Tuff & Light"

Satoshi ITO ► Chief Manager, Civil Engineering Technology Division, OBAYASHI CORPORATION)

Motonori KAMEYAMA ► President, KAMEYAMA CORPORATION

The standard forepiling method (AGF method) uses a steel pipes of ϕ 114.3mm in outer diameter and t=6mm in thickness are driven into the upper part of the tunnel face prior to excavation work to reinforce the bedrock. Four 3-m-long steel pipes connected as a 12-m section are driven into the rock at each location. As each 3-m-long pipe weighs 50 kg, it was a heavy burden for the workers.

So, we developed a lightweight steel pipe for AGF that uses high-strength materials, which are increasingly being applied in the automotive and other industries. The quality of the new pipe is equal to or better than conventional AGF pipes, while being thinner and lighter in weight. This reduces the burden on workers and improves productivity and safety.

Photo 1 A Cross-sectional Comparison of the Conventional Steel Pipe (left) and the New AGF Tuff & Light Pipe (right)

Features of AGF Tuff & Light

(1) Thinner pipes from using high-strength material

AGF Tuff & Light uses high-strength materials with tensile strength of 730 N/mm^2. The thickness of the steel pipe is reduced from 6mm to 3.5mm, and the weight per pipe is reduced from 50kg to 29.4kg (60%).

(2) Improved quality of joints (threaded sections)

The threaded portion is specially processed to ensure higher quality than the bare portion of conventional AGF steel pipe (bending strength: 53% higher, tensile strength: 15% higher).

Table 1 Comparison of bending and tensile strength of AGF Tuff & Light and conventional steel pipe

	Bending	Tensile
AGF Tuff & Light Threaded portion	18.8kN.m*	550kN*
Coventional AGF Bare portion	12.3kN.m	480kN

*Actual measures

(3) Reduced construction time

Construction time of the AGF method can be reduced by 10% because of the weight is less.

Photo 2 AGF Tuff & Light Being Used in Construction

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Development and application of automatic construction system for tunnel-secondary lining

Shuji MATSUMOTO ► KAJIMA CORPORATION

Background

In the placement of tunnel lining concrete in Japan, a concrete with a slump of about 15 cm is placed into a narrow and closed space with a lining thickness of about 30 cm, and internal and formwork vibrators are manually operated for compaction work. On the other hand, the construction industry in Japan suffers a huge shortage of skilled workers due to aging, and to make up for these problems, encourages mechanization and automation of construction works. There is an urgent need to mechanize painful human efforts in lining concrete placing.

Summary of the System

We have developed a new concrete placement pipeline system and an automatic concrete-placement system in combination with a concrete pumping truck utilizing interlinking technology. The automatic concrete-placement system for tunnel lining, as shown in Fig.1, is composed of four elements. A: high-fluidity lining concrete which requires no compaction, B: a new concrete-casting pipeline system to facilitate the recovery of waste concrete, C: high-speed pipeline switching system, and D: a placement control system which is designed to regulate the concrete height automatically.

By automatically controlling Systems B and C, System D is able to place concrete from the center of the lining formwork without human intervention and to automatically adjust the concrete height of the left and right linings.

Furthermore, the casting situation was able to be delivered over the network, demonstrating the capability that placement can be monitored remotely and to be utilized as a model of actual lining work.

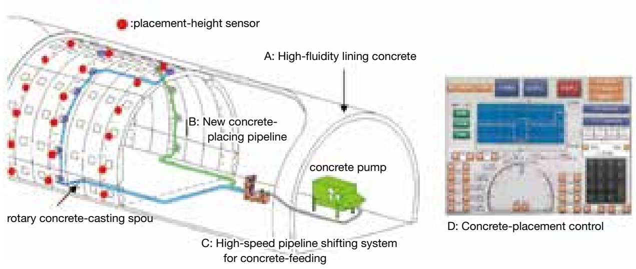

Fig. 1 Diagram of the automatic lining concrete-placement system

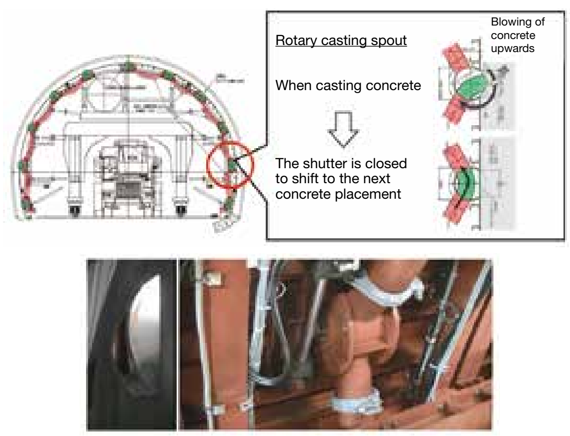

Fig. 2 New concrete placing pipeline

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Continuous concrete pouring system using extending/retraction-type hose to improve quality and save resources while placing lining concrete in tunnels

Hideaki NISHIURA ► Manager, Tunneling Technology Department Civil Engineering Technology Division, OBAYASHI CORPORATION

In Japan, placement of lining concrete is done simultaneously with tunnel excavation work. To do so, space must be secured for tunneling vehicles to pass through the travelling form while lining concrete. As shown in Fig. 1, steel concrete pipes placed within the form shall be switched over to the next casting height by man power.

This method increases drop height from concrete pouring pit right after pipe switching. This causes risks of material separation of concrete or engaging excess air in it. Any delay in the switching operation could cause a risk of cold joints since the placing would not be finished in time. Also, a great deal of labor is required to move the heavy steel piping within the narrow construction space.

As shown in Fig. 2 and Photo 1, the new system enables continuous concrete placement without switching steel pipes by pulling up the concrete placement hoses on the left and right sides to the next placing height automatically. With this method, concrete is poured at the minimum drop height, which prevents material separation and excess air entrapment, eliminates excessive pouring time, and reduces the strenuous workload switch pipes.

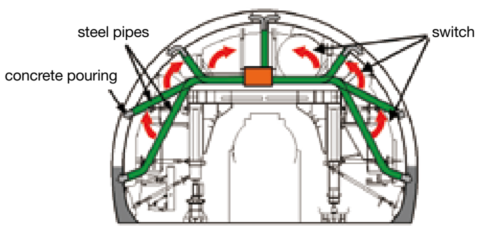

Fig. 1 Conventional method

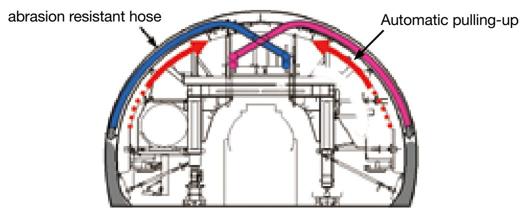

Fig. 2 New method

Photo 1 Panoramic view of continuous concrete pouring system using extending/retraction-type hose

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"A.E.s.SLic" AI Technology that Automatically Evaluates the Surface Quality of Lining Concrete

Takayoshi SHIINA ► Group Leader, Technical Research Institute, Nishimatsu Construction Co., Ltd
Yusuke TAKAGI ► Chief Researcher, Technical Research Institute,Nishimatsu Construction Co., Ltd.

Overview

Nishimatsu Construction Co., Ltd. and sMedio, Inc. have jointly developed an artificial intelligence (AI)-based technology called "A.E.s.SLiC" that automatically evaluates the quality of concrete surface layers based on photographic data of lining concrete. This technology enables stable judgments that are not affected by the skill level of the evaluator and can also be used to identify areas requiring improvement in construction methods and to formulate remedial measures.

Specification

This system is structured with a tablet machine, a cloud-based server, and a PC terminal. The AI system is cloud-based, and when a photograph of the concrete lining surface taken with a tablet or digital camera is input into the AI system, the system automatically evaluates the quality of the concrete surface layer and outputs the results. The AI system automatically evaluates six items, including surface bubbles, peeling, and color irregularities. Each item is scored in five levels, with the low-scoring areas requiring improvement indicated on a diagram of the concrete lining. The evaluation points can be output as a time-series graph or table, which can be used as a tool to determine the effect of quality improvement.

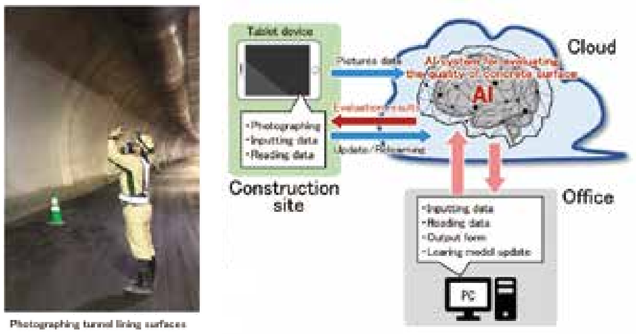

Fig.1 Conceptual diagram for AI system

Fig.2 Sample of a Processed Image (Left: Original Right: Processed)

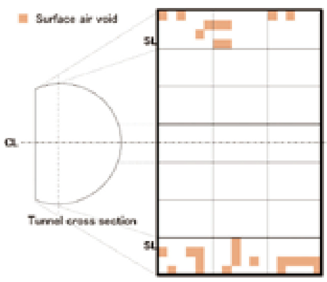

Fig.3 A Diagram Image Showing Lining Parts that Need Improvement (surface bubbles)

An Automatic Tunnel Lining Concrete Construction Robot System for Practical Use

Kousuke KAKIMI ► General Manager
Yasuo IDE ► Groupe Manager
Futoshi KUSUMOTO ► Engineer
SHIMIZU CORPORATION
Civil Engineering Technology Division, Underground Section,

The "Automatic Tunnel Lining Concrete Construction Robot," which replaces manual tunnel lining concrete work with a PC-controlled, automatic mechanical system (joint development by West Nippon Expressway, Shimizu Corporation, and Gifu Kogyo), has been put to practical use. The robot uses medium flow lining concrete, which has excellent flowability and does not cause material separation. The system also takes advantage of the characteristics of medium flow lining concrete to achieve one-man automated concrete placement using a shotcrete pouring system.
All operations such as concrete pumping, pipe switching, movement of the placing equipment to the placing entrance, and formwork vibrator compaction are patterned and controlled by a PC system to achieve automatic construction (Fig. 1, Photo 2). The work status and compaction state can be visualized and monitored by real-time data from various sensors attached to the centers, and the execution status can be stored in a database.
The finished surface of the lining by the automatic installation of the automatic compaction system with the automatic pouring system and formwork vibrator pattern is excellent, with no peeling, bubbles, uneven coloring, or overlapping lines, and this installation method has finished linings with a small variation of concrete strength (Photo-2).

Photo 1 Automatic Concrete Lining System

Photo 2 Tunnel Lining

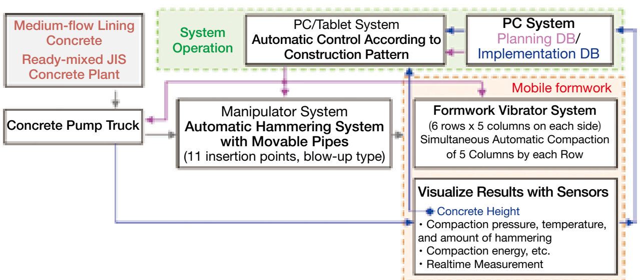

Fig.1 Automatic Construction System Using Medium Flow Lining Concrete

"Spacepack®" : A Tunnel Lining Backfill Grouting Method

Kenji Akiyoshi ► Senior Chief Engineer
Civil Engineering Construction Division,
OBAYASHI CORPORATION

The Spacepack is an injection method using one-component and two-component plastic grout (Photo 1) suitable for filling cavities in the back of tunnel linings and under road surfaces. By filling cavities in various structures, the grout restores their functions and contributes to extending the service life of tunnels and other social infrastructures. The features of this method are as follows:

1) The method is cost beneficial because it uses inexpensive materials and can be implemented using general-purpose machinery.
2) The material has moderate fluidity and shows little shrinkage and segregations, which makes it reliable as filling.
3) Material loss can be minimized since the material can be used for limited injection, and there is only small material leakage from cracks in the lining and construction joints (Photo 2).
4) Stable quality can be ensured even in cavities underwater or filled with spring water (Photo 3).
5) The material can be pressure fed up to 2,000m away, allowing flexible choice of manufacturing system that suits the conditions for construction.

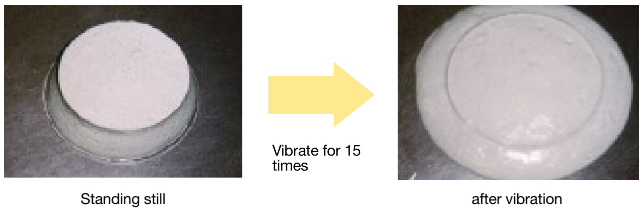

Photo 1 Plastic grout

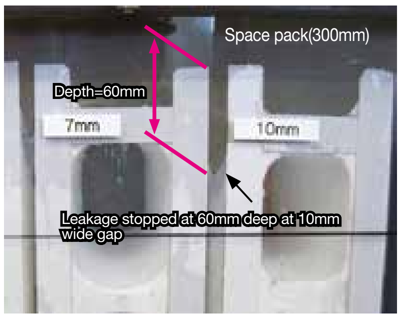

Photo 2 Leakage proof

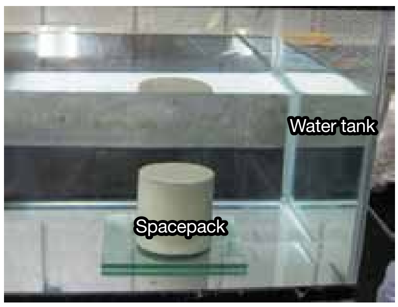

Photo 3 Resistant to segregation under water

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Automatic Spreading System of Long Waterproof Sheets

Arisa SAITO ▶ Senior Manager
Civil Engineering Technology Division
OBAYASHI CORPORATION

There are concerns that Japan will face a shortage of mountain tunnel engineers and skilled laborers as the population declines with the falling birthrate and the increasing ageing population. Obayashi Corporation is working to develop an automated mountain tunneling system that can be applied to all types of mountain tunnel construction sites, to respond to needs for automated technologies that will further improve productivity.
One of these technologies is the "automatic long tarpaulin spreading system," which was developed as a "tarpaulin spreading technology" in the field of lining technology.
By using a 10.4-meter-wide long sheet, this system can reduce the welding length at the construction site to one-fifth of the conventional length, thus ensuring the quality of waterproofing. In addition, a newly developed special device can ensure the adequate margin required when spreading the waterproof sheet.
After folding the tarpaulin, the roll of tarpaulin (Photo 1) is pulled up on the curved base of the work truck, and then the truck is moved forward to spread the tarpaulin, which is then automatically spread by pressing it against the wall surface with a balloon (Fig. 1).
This system enables rapid and labor-saving installation of tarpaulins in mountain tunnels, while ensuring the quality of the work. It has been confirmed that the use of automatic spreading and long tarpaulins has improved work efficiency by about twofold.

Photo 1 Rolled Waterproof Sheet (pulling up)

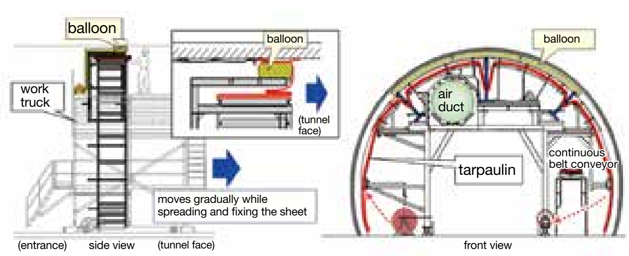

Fig. 1 System Outline

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Measurement System for Groundwater Inflow Rate and Pressure in Advanced Boring
—T-DrillPacker®—

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Outline

To ensure the safety and workability of mountain tunnel construction projects where large amounts of water inflow occur, it is important to know in advance the status of the water inflow in front of the face. T-DrillPacker is a new survey technology that can quickly and reliably measure the amount of water inflow and water pressure without having to pull out the borehole pipe after identifying the location of water inflow using advanced boring techniques.

Process

Drilling is performed with a double bit with an outer bit on the outside and an inner bit on the inside. When measuring water inflow, only the inner bit is recovered at high speed using the wireline method, and the packer is inserted from inside the outer bit. A large expansion packer that expands from the inner diameter of the outer bit to the hole wall is used.

Features

1) Measurement time can be reduced by 20% compared to the conventional method because the drilled pipe is not collected.
2) The drilled hole pipe plays the role of protecting the borehole wall, enabling reliable surveys without the risk of borehole wall collapse.
3) Drilling can be easily continued by retrieving the packer, pumping the inner bit with water, and re-setting it.
4) By changing the double bit to a bit for core sampling, it can also be applied to core boring.

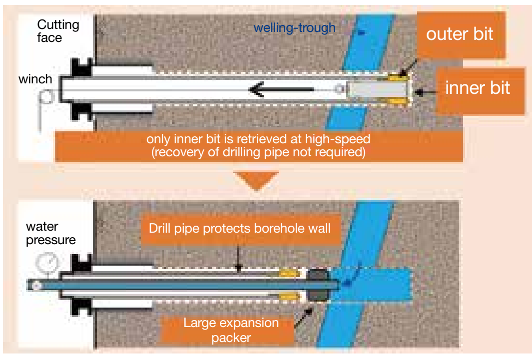

Fig. 1 Method of Measurement

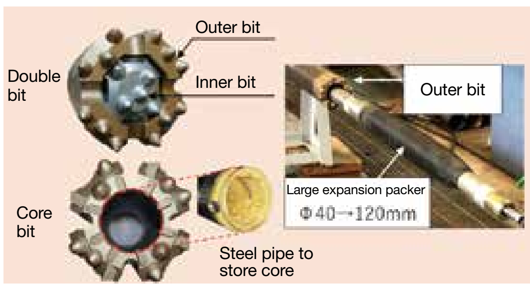

Fig. 2 Bit and Large Expansion Packer

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MOLE-FMR (Field Mixed Reality) & FCM (Field Crack Mapping)

— MR Aided Tunnel Inspection System —

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1. Introduction

It requires a lot of inspectors to conduct a tunnel survey within a limited period, which is extremely inefficient. One of the major reasons is the difficulties of detecting cracks and defects on the weathered tunnel lining and measuring their shape and position. We have greatly improved the efficiency and accuracy of the tunnel inspection work by using MR (Mixed Reality) technology.

2. Tunnel survey guiding system: MOLE-FMR

We have accumulated the obtained survey data of the tunnel into a database with a data structure linked with location information (MOLE-LTR). A 3D-CG model of the cracks and the defects can be automatically created from the database (MOLE-DMG). When the CG model is created and transferred to the MR device, the cracks and the defects are projected on the on-site tunnel surface in their original shape and position and it is easy to identify them. With the introduction of MOLE-FMR, the tunnel inspection work time has been reduced to less than 1/3 of its conventional time.

3. Digital crack sketching system: MOLE-FCM

By projecting a grid with known intersection coordinates onto MR space, the digital coordinates of arbitrary point inside the grid can be identified. MOLE-FMR is a system that measures the shape and the position of cracks and defects using this geometric relationship. The advantage of this system is to map the position and the shape of cracks as digital data simply by taking a wall image with the grid projected through the MR device. Moreover, it can detect crack growth with the accuracy of several centimeters.
The MR-assisted tunnel inspection system takes less than a quarter of the time required for tunnel surveys compared to conventional methods, allowing two people a day to survey small water tunnels of 150 m or more.

Fig. 1 System diagram of MOLE-FMR

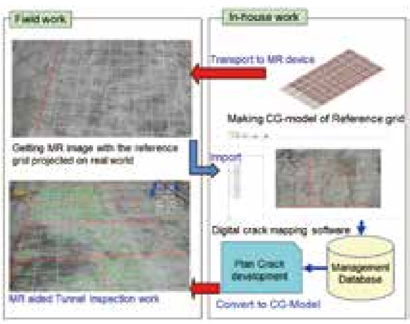

Fig. 2 System diagram of MOLE- FCM

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Adopting "Safety 2.0" to Construction Work

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Mountain tunneling repeats the cycle of drilling, loading, shearing, spraying, erection of steel supports, and rock bolting. The work is divided into three categories: work with heavy machinery only, work with people and heavy machinery, and work with remote operation of heavy machinery. Each area is divided into dangerous and safe zones for safety control, but the final safety control depends on human judgment. Recently, with the advancement of information and communication technology (ICT) has made information sharing between people, objects, and the environment possible to ensure safety. This concept is called "Cooperative Safety," and the technological aspect that supports this concept is called "Safety 2.0" (Fig. 1). In mountain tunneling, work areas are zoned according by time and space, and the positions of people and heavy machinery are digitally monitored (relative position detection and image analysis). Safety 2.0 technology, such as alerts that can be recognized by humans and machines and immediately shutting down heavy machinery, is implemented to prevent contact accidents (Fig. 2). In this way, we believe that Safety 2.0 technology can enhance the wellbeing of the people working there by realizing safety and security through the cooperation of people, machines, and the environment.

※ Ref. Masao Mudaidono, "Safety and Assurance for the New Era: Safety 2.0 and Cooperative Safety)," Hitotsubashi Business Review 2019 WIN, pp.8-17, Toyo Keizai Inc. (Dec. 2019).

Fig. 1 Outline of Cooperative Safety

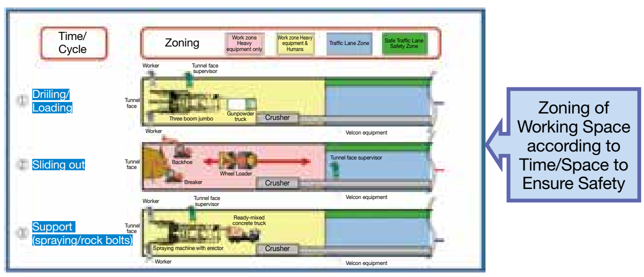

Fig. 2 Zoning Sample of Working Space for Tunnel Construction

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Blast Master: The System that Reduces Excess Digging and Makes a Smooth Excavation Surface

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Introduction

Our understanding is that even if accurate drilling is repeated according to a predetermined blasting pattern using a computerized jumbo, the effect of reducing the amount of extra excavation is limited due to the effects of heterogeneity of the ground and bedrock cracks. In fact, experienced and skilled technicians have been able to reduce the amount of extra excavation by controlling the drilling angle (angle of insertion) individually to form a smooth excavation surface.
As shown in Figure 1, the authors have succeeded in systemizing the conventional skillful technique by combining a technique for quantifying the amount of remaining excavation using a three-dimensional scanner and a technique for calculating the optimum angle of insertion according to the amount of remaining excavation. As a result, the authors were able to demonstrate that the amount of excess excavation can be reliably reduced.

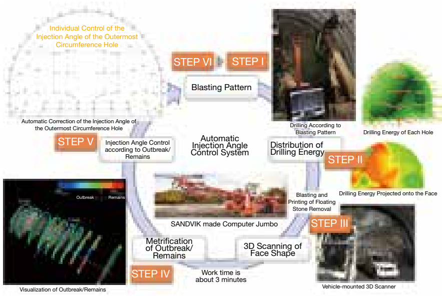

Fig.1 Configuration of the BLAST MASTER

1. Introducing Blast Master

BLAST MASTER reduces the amount of excess digging step by step and reliably by repeatedly learning the following steps.
Step I: Blasting patterns are created and displayed on the computer jumbo control screen (the first blasting pattern is set based on past experiences and the strength of natural ground, etc.).
Step II: The jumbo operator accurately drills the face according to the blasting pattern (the drilling energy is automatically calculated and recorded at this time).
Step III: After loading, blasting, and shearing, floating stones are removed, and the safety of the cutting face area is checked. Then a vehicle-mounted 3D scanner is set in front of the cutting face to scan the shape of the face immediately after excavation (this takes about 3 minutes).
Step IV: Scan results are quantified and visualized on the spot to check the amount of extra digging/perturbation (if perturbation is present, it is removed on the spot).
Step V: Automatic calculation of the angle compensation value based on the pre-defined "relationship between digging margin and angle compensation value" (compensation value is independent of the soil properties).
Step VI: Correction values are reflected in the blasting pattern for the next cycle, and the blasting pattern is automatically created (Go back to Step II)

2. Results

(1) Excess Digging Reduced
The application of BLAST MASTER for multiple cycles resulted in a reduction of approximately 69% in the maximum amount of excess excavation and approximately 78% in the average amount of excess excavation. Although the reduction effect of the amount of excess excavation varies depending on the ground conditions, we were able to demonstrate that the system can reliably reduce the amount of excess excavation by systematizing a skillful technique.
(2)Preventing Disasters at Cutting Edge
Drilling energy is an objective indicator of the geotechnical properties distributed in the face. BLAST MASTER utilizes this indicator for preventing face failures. This indicator does not necessarily guarantee safety. However, it is important to share this information, which cannot be obtained by visual observation alone, with all tunnel personnel, including face supervisors and face workers, immediately after drilling. In fact, this information gives workers a sense of psychological security and has been evaluated to a certain extent.

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An On-site batcher plant that automatically controls concrete mixing temperature Smart Batcher Plant®

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Summary

Smart Batching Plant® is an on-site batching plant that can automatically control the concrete mixing temperature and produce concrete at a stable and optimal temperature even in cold climates where the minimum temperature reaches 20° C below zero. This allows the plant to maximize the performance of shotcrete and achieve stable adhesion and strength development throughout the year.

Main Features

Figure 1 shows an overview of the system.
The automatic control of mixing temperature consists of three functions.
Function I: Heating of water, fine aggregate (sand), and coarse aggregate (crushed stone)
Function II: Accurate temperature measurement before mixing and continuous temperature measurement during mixing.
Function Ⅲ : Control function that automatically adjusts the ratio of raw water (cold water) to hot water according to the target mixing temperature.
The greatest features of this function are Functions II and III. It measures the temperature of water (raw water and hot water), aggregate, cement, and concrete during mixing, calculates the heat capacity required for the target mixing temperature based on the measured values, and automatically adjusts the amount of hot water and raw water to be added.

Application Example in Cold Climates

Figure 2 shows the results of application in a cold region where the minimum temperature reaches 20° C below zero. Regardless of changes in ambient temperature, the target kneading temperature of 25° C was achieved. By eliminating the use of excessive addition of a quenching agent, shotcrete with good strength development and high quality with little rebound was achieved.

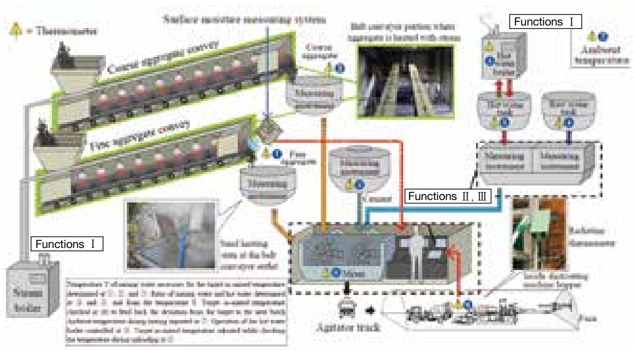

Fig.1 Outline of the Smart Batcher Plant system

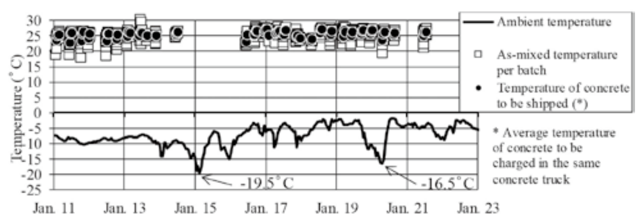

Fig.2 Changes in concrete as-mixed and ambient temperatures over time

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