Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2020

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 2020 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 recent years has made it possible to construct long tunnels and large section tunnels safely 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, on the other hand, 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. Based on such recent specific examples, this booklet presents a selection of some typical examples representative of the numerous tunnel projects and technological developments in Japan I will be pleased if these articles prove useful for tunnel engineers around the world.

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Tunnel Activity 2020 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.

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

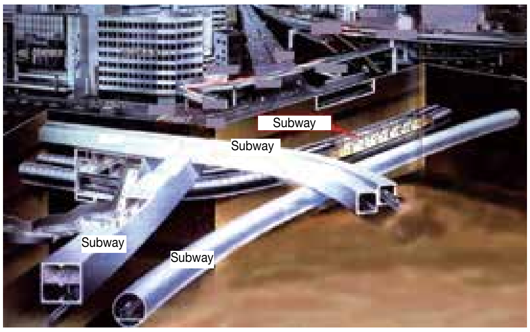

Fig.-2.2 Advanced Usage of Underground Space in a Large City (Around Iidabashi station, Tokyo)

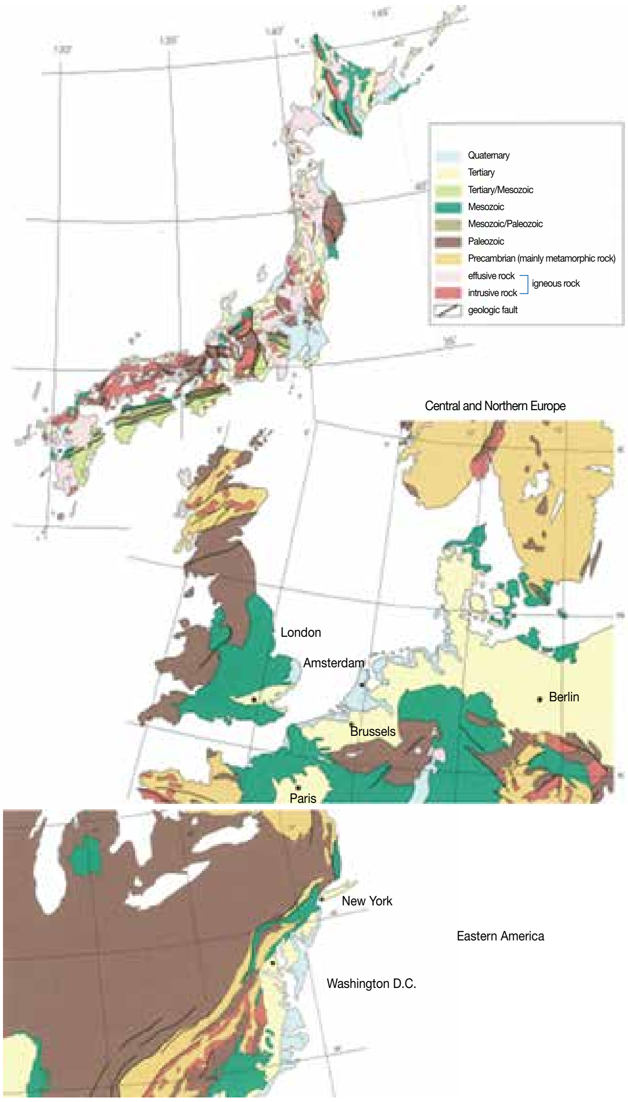

Fig.-2.1 Differences of Geology of Japan and the Western world

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

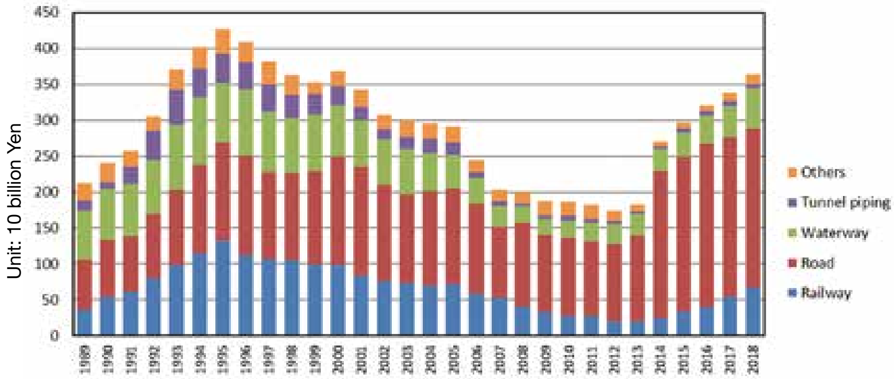

Fig.-3.1 Trend of construction investment in tunnels and underground space

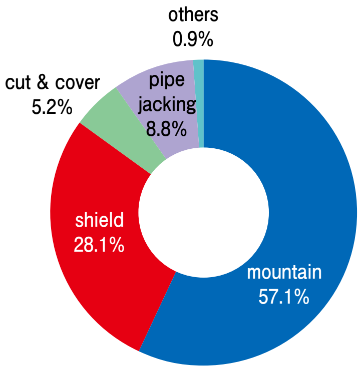

Fig.-3.2 Ratio by Tunnel Construction Method

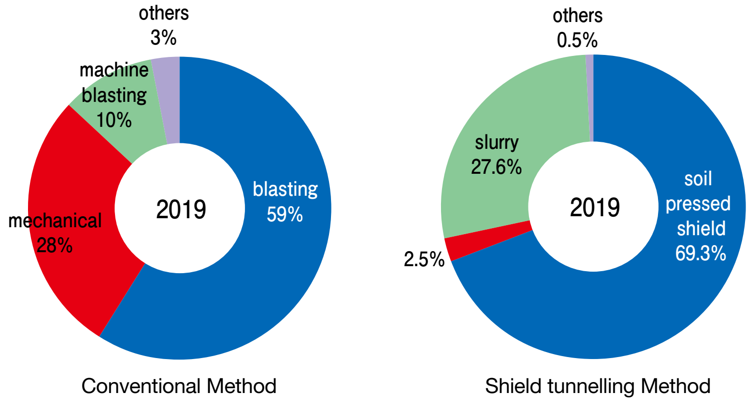

Fig.-3.3 Ratio of Tunnel Construction by Method

investment due to reconstruction efforts starting in 2014 after the Great East Earthquake and the construction for 2020 Tokyo Olympic and Paralympic Games.

Fig.-3.2 and 3.3 shows the trend of construction investment in tunnels and underground space by type. Mountain tunnels are 57%, with 60% of that using blasting. Shield tunnels consist of 28% 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 2017, there are approximately 11,000 locations with a total of 4,500km of tunnels built in the road system (Fig.-4.1). The percentage of tunnels over 50 years is around 21%, which will increase to around 35% in the next ten years.

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.

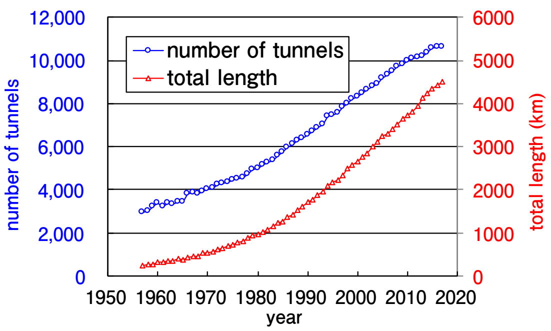

Fig.-4.1 Number and Length of Road Tunnels in Japan

(2) Railway Tunnels

As of 2015, the total length of railways owned by the seven JR group companies (former national railway) has become 20,117km. There are 3,627 tunnels, consisting 2,462km 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 (2015), MILT

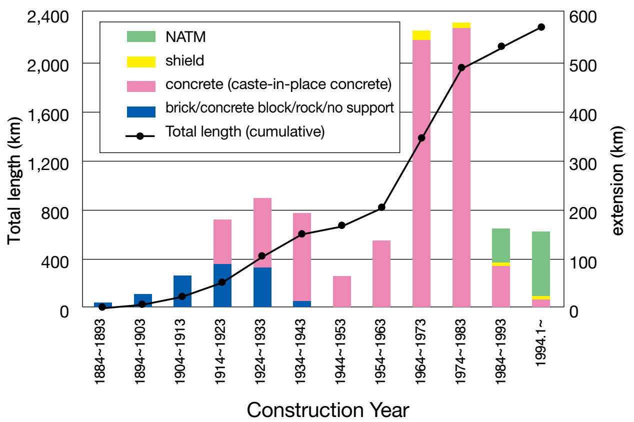

Fig.-4.2 Number of tunnels constructed by the seven JR companies (former national railway) by year (as of 2002)
Source:"Tunnel Library 14 Tunnel Maintenance in Japan", Japan Society of Civil Engineers, July 2005

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Constructing a Tunnel by NATM with Minimum 5m Covering Under a Dense Residential Area, while Considering the Surrounding Environment

— The Shin-Nagasaki Tunnel (West) Construction Site, Kyushu Shinkansen West Kyushu Route —

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Japan Railway Construction, Transport and Technology Agency (JRTT)

Introduction

Kyushu Shinkansen (West Kyushu Route) is a high speed railway route that connects Fukuoka and Nagasaki Prefectures in the Kyushu island of Japan. Currently, construction of the about 67km part between Takeo Onsen (in Saga prefecture) and Nagasaki is going underway, to be finished in fiscal year 2022. The Shin-Nagasaki Tunnel (West) is a 7,460m long double-track cross section mountain tunnel. The Shin-Nagasaki Tunnel's (West) Construction site is the 3,575m part including the end point side of the tunnel. At this construction site, excavation was done in area A, right under a densely built residential area with minimal covering of 5m, and directly under area B, with minimal covering of 7.5m (Fig. 1 & Fig. 3). Challenges during excavation were the effects of the construction to the houses and other buildings, as well as steep slopes in the area of small overburden, and need of consideration to the residents living there. This report details about the measures taken to prevent land subsidence, percussion, and noise, and construction conditions of a tunnel directly under a densely built residential area with small overburden.

1. Countermeasures to Prevent Land Subsidence During Excavation with Small Overburden

A Finite Element Analysis (FEA) was conducted due to concerns that the natural ground of surrounding the tunnel might loosen and create a subsidence during excavation, which would then affect the houses and steep slopes above the tunnel. The analysis showed that the ground loosened around the area near the ground surface where overburden was less than 10m, raising concerns of the stability of the crown and tunnel face (Fig. 2). After calculating the load of loosen bedrock, steel forepiling (ϕ 114.3mm, t=4.2mm, L=12.5m@450mm, silica-resin) was used in the area of overburden less than the diameter of the tunnel (Fig. 3). The support pattern where steel forepiling was used is shown in Fig. 4. The area of steel forepiling was determined by considering the effects of collapse at 45 degrees in the direction of the tracks, and set up an allowance section of total 20m (10m+10m) at the starting and end points of the area where overburden was under 1D. Twenty-four-hour measurements were done during excavation, including land subsidence measurement by the total station, an extensometer, and placement of a land monitoring personnel in addition to convergence measurements.

2. Reducing Percussion and Noise

The ground of the area with small overburden mainly consisted of andesite and tuff breccia. As the uniaxial compressive strength of the natural ground was around 22.4 ~ 76.8N/mm^2, categorized as soft rock to hard rock, making blasting system the usual choice. However, due to concerns of affected the houses built on the ground surface, and complaints from residents, a 350kw-grade boom type cutting machine (Photo 1), capable of cutting through hard rock was used to reduce percussion and noise during construction. Also, with due regards to the life-style conditions of the residents of the area, twenty-four-hour work was deemed difficult, and the construction was done only during the day.

3. Construction Results

Amount of land subsidence, noise/percussion rates were limited within control levels in both areas A and B (Tab. 1). In addition, there were no significant complaints from surrounding residents, and no damages were noticed from the houses that stood on the surface. Excavation work safely finished in October 2018, and installation and other works are being done to meet the launch in 2022.

Fig. 1 Surface Condition of Area A

	Items of Analysis	Cross section ① (Area A)	Cross section ② (Area B)
Preconditions	Overburden	5.0m	9m
	Condition of Natural Ground	Andesite with multiple cracks	Andesite with multiple cracks
FEA Results	Land Subsidence	3.1m	4.6m
	Crown Subsidence	3.7m	6.0m
	Stress Severity 0.3 0.0		
Observation	Areas where overburden is 10m or less has possibility of crown collapse that effects near to the land surface.		

Fig. 2 FEA Results

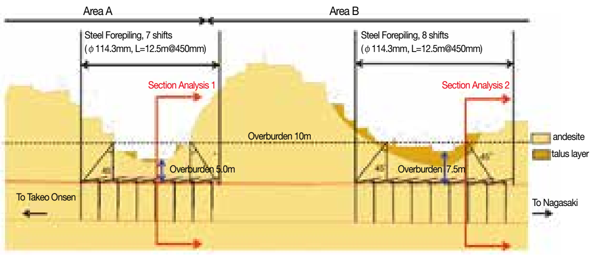

Fig. 3 Scope of Steel Forepiling

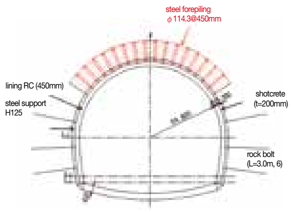

Fig. 4 Support Pattern where Steel Forepiling was Used

Photo 1 350kw-grade boom type cutting machine

Tab. 1 Measurements

	Amount of Land Subsidence		Surface Noise		Surface Percussion	
	Control Value	Measured Value	Control Value	Measured Value	Control Value	Measured Value
Area A	-50mm	-2mm	85dB	66.3dB*1	77dB	58.2dB*1
Area B	-50mm	-2mm	85dB	77.6dB*2	77dB	72.9dB*2

*1 Measured at surface of section where overburden was 5m
*2 Measured at surface of section where overburden was 7.5m

Neighboring Construction of a Long and Massive Mountain Tunnel's Fault Crush Zone

― The Shin-Hokuriku Tunnel of the Hokuriku Shinkansen ―

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1. Introduction

Hokuriku Shinkansen is a high speed railway that covers 690km from Tokyo to Osaka, with about 125km between Kanazawa and Tsuruga stations being under construction. Shin-Hokuriku Tunnel is a 20km long, long and large-scale mountain cross section tunnel for multiple Shinkansen tracks. The tunnel is divided in six zones constructed by NATM (Fig. 1).

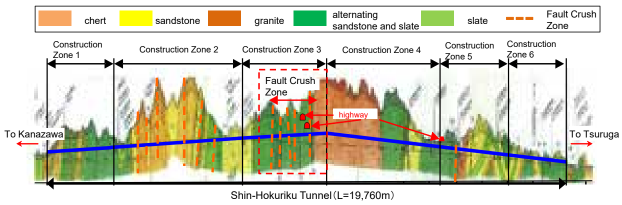

Fig. 1 Shin-Hokuriku Tunnel's Geological Profile

2. Features and Plan of the Tunnel

There are three main geological characteristics of this tunnel. One is "the ground consisting of "complex alternations mainly consisting of chert, sandstone, granite, and slate", and secondly, "multiple faults intersect, resulting in rapid changes of geology", and "ground water accumulates inside the cracks of rocks crushed by the faults". The business requirements, namely the deadline to launch the Shinkansen, has put the construction work under severe conditions such as rapidly finishing the excavation of the fault crush zone while paying consideration to surrounding environment and future sustainable management of the tunnel.

When excavating a fault crush zone directly below an existing highway tunnel for about 40 meters, crushed clay and a high amount of high-pressure water flow into tunnel is found (Fig. 2). So increased carefulness and consideration of safety is necessary in order not to disrupt the highway, which is an important trunk road. Finite Element Analysis (FEA) has been conducted beforehand to assess the amount of settlement and pressure on the lining, along with plans to measure and compare during excavation. In addition to using steel forepiling and long steel face bolt are adopted as auxiliary methods, closure using initial invert within three days after start of excavation is planned so early closure will minimize any influence on the existing tunnel (Figs. 3 & 4).

Fig. 2 Condition of the Fault Crush Zone during Excavation

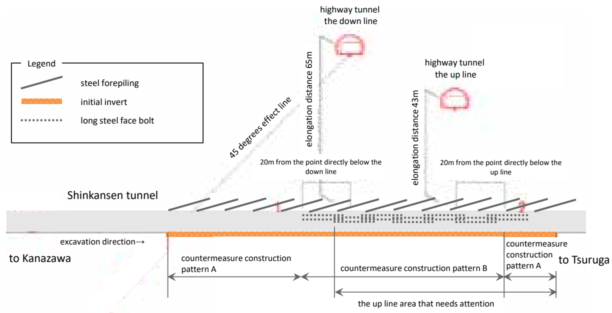

Fig. 3 Excavation Plans Directly under Existing Tunnel

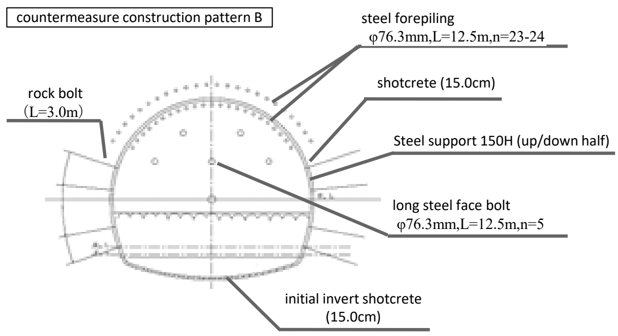

Fig. 4 Excavation Pattern

3. Construction Results

Excavation of the fault crush zone that intersects with the existing tunnel resulted in changed convergence measurement of a maximum of around 100mm. The stress on the settlement and lining of the existing tunnel was smaller than the FEA value estimated before construction. One reason for this is assumed that the various auxiliary methods combined to minimize the influence on the natural ground, and such prudent construction has helped to make the plasticity caused by excavation significantly smaller.

As of October 2019, 96% of the excavation is finished. Though the condition of natural ground rapidly changes, we will keep up the prudent and safe construction work by repeating the cycle of careful forecast at planning stage, measurement during excavation, and post-work assessment.

Construction of SCL Tunnel with Ground Freezing Underneath Existing MRT Tunnels in Singapore

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A Marina Bay Station is part of new Thomson East Coast Line and constructed in southern part of Singapore. There are two existing MRT Tunnels, North South Line (NSL) and Circle Line (CCL), operating within the proximity of the new construction area. New railway tunnels were constructed by SCL (Sprayed Concrete Lining) method directly underneath these two existing 'live' MRT tunnels with vertical alignment (Fig. 1). Ground Freezing method was used to cut off the underground water for safe tunnel excavation. This was the first time that the Ground Freezing had been applied for an underground railway project in Singapore. The advanced 3D FEM Analysis was carried out to predict the movement of the existing MRT tunnels caused by the Ground Freezing and SCL Tunnel excavation.

Fig. 1 Freezing Pipes

1. Ground Freezing

The subsurface conditions consist of hydraulically reclaimed Sand Fill followed by Kallang Formation which includes Marine Clay. This is underlain by Silty Sand Layer, so-called Old Alluvium (OA). The Kallang Formation which are very soft and unstable was all treated by JGP (Jet Grouting Pile) and the upper SCL tunnel was excavated all the way in the treated JGP. Because of the density and potentially flowing characteristic of the underlying OA, the JGP could not be enough to stabilize this deposit and Ground Freezing was adopted to stabilize the zone at the interface of the Kallang Formation and the OA. Ground Freezing Pipes (GFP) and Temperature Monitoring Pipes (TMP) were installed from the inside of the Linkway tunnel which was constructed directly above the subsequent two SCL Tunnels. A total 96 of GFP (Bluer Arrow) and 20 of TMP (Red Arrow) were installed (Fig. 2). The length of pipe of GFP and TMP was 26 m and the spacing of GFP was basically 0.9 m except for 1.2m at the existing NSL pile (OD 1.0m). The brine comprised of calcium chloride, CaCl2 and was cooled by Refrigeration Unit set at ground surface. The brine was chilled to a targeted temperature of -30 oC and was pumped down to the bottom of the GFP buried in the targeted freezing zone in the ground. The monitoring of the growth of the frozen soil was carried out carefully by 2D temperature distribution map and 3D data using BIM based on the actual temperature data from TMP.

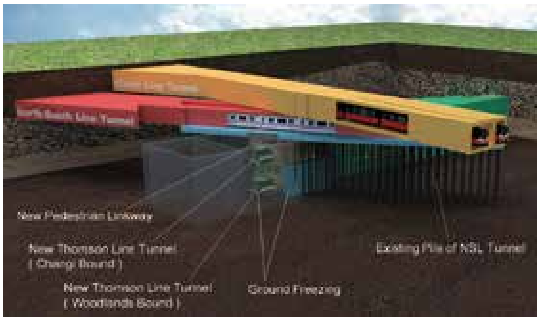


Fig. 2 3D Section Wide view black

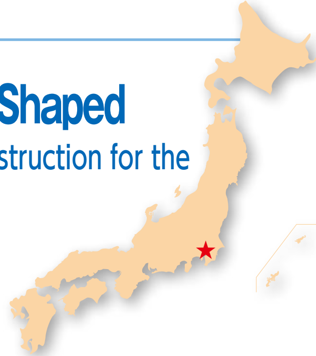
2. Construction of SCL Tunnel

The excavation of lower SCL Tunnel commenced after the confirmation of the targeted form of the frozen soil wall based on the temperature monitoring. The diameters of tunnel excavation were 7.0 m (Lower Tunnel) and 7.1 m (Upper Tunnel). The primary shotcrete (G30) thickness was 300 mm. The Tunnel cutting face was divided into 2 parts for safe excavation, i.e., the top heading and bench/invert (Photo. 1). The surface of the frozen soil was encountered and some of GFP were exposed adjacent to the existing barrette piles during the tunnel excavation. The insulation sheet was placed on the surface of the frozen soil and GFP before the shotcrete was applied to ensure the quality of the shotcrete. The construction sequence was the activation of ground freezing, the excavation of lower tunnel, the de-activation of ground freezing, the excavation of upper tunnel and the lining of both tunnels.

Photo 1

3. Conclusion

One of the critical concerns was the excessive movement of the existing MRT tunnels caused by Ground Freezing (Frost Heave and Thaw Shrinkage) and SCL Tunnel excavation. Construction control was achieved based on actual monitoring data compared to predicted values by FEM analysis, and the work was completed successfully without breaching the Work Suspension Level.



Construction of an Underground Passage with a Rectangular Shaped Muddy Soil Pressure Balanced Shield Machine — Public Facility Construction for the First-type City Redevelopment Project, Toranomon 1-chome District —

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Introduction

A large-scale redevelopment is underway in the Toranomon area of Tokyo in preparation for the Tokyo 2020 Olympic and Paralympic Games. To improve the traffic connection in the surrounding area, a pedestrian underpass connecting the stations of two subway lines is being developed.

The underground passage of about 370 meters in length is to be constructed by three methods; closed-face shield TBM, pipe jacking, and cut and cover. For the section of about 218 meters out of the total length, muddy soil pressure balanced shield TBM method with rectangular cross section (external diameter: W = 7.92 m, H = 5.02 m) was applied.

1. Characteristics of This Project

The earth covering above the shield tunnel is from 3.0 meters to 5.6 meters, and the target excavation ground is soft alluvial viscous soil with N-value of about 0 to 2. Right above the tunnel are several important underground utilities and close to the sides are many low-rise buildings. The shield vertical alignment changes from an upward 0.28% slope to an 4.46% slope (Vertical Curve R = 500 m).

2. Challenges and Solutions

The challenges in this project are: I. Suppression of ground deformation and suppression of influence on underground utilities and surrounding buildings, and II. Attitude control of the shield machine. For the task I, to suppress the influence of shield drilling on underground installations and low-rise buildings, the ground improvement by the high pressure jet stirring method was carried out in the upper and side portions of the tunnel. In order to suppress the ground deformation, controlling the earth pressure and the amount of discharged soil is crucial and thus to check the validity of the set earth pressure, stratified settlement gauges were installed at 10 meters and 30 meters from the launching shaft, and the excavation was carried out while confirming the underground displacement in real time. For the muck discharge, a pumping system was adopted, and the discharge amount was controlled with a flow meter and a density meter installed in the pumping pipe. In addition, a simultaneous grouting device was installed on the upper part of the shield machine, and backfill grouting was carried out immediately whenever tail voids were generated.

For the task II, to deal with the vertical curve, the shield machine was equipped with an articulation unit (with angles 1.0° up and down). In addition, the rolling of the shield machine was controlled by adjusting the amount of overcut by the extensible cutter built in the spokes, selecting appropriate shield jacks, injecting the filler from the lower body of the shield machine and using the articulation unit. With these methods, successful construction under the special condition — soft ground covered with small earth covering and the use of rectangular shield — was achieved, resulting in the high accuracy of "ground surface subsidence: within 10 mm (negotiated control value), finished shape of the tunnel: within ± 50 mm (upper, lower, left and right tolerances)."

Photo 1 Rectangular shaped muddy soil pressure balanced shield machine

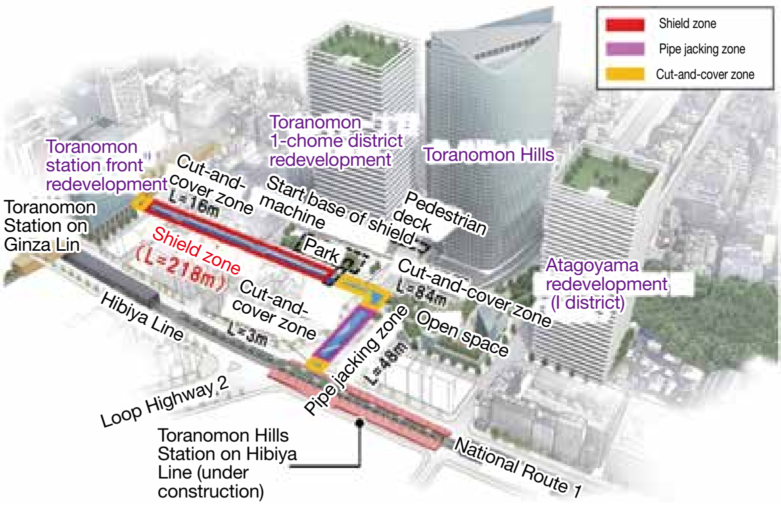

Fig. 1 Construction location map

Building a Crossing under Railway Using HEP&JES Method at a Terminal Station

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Railway Headquarters, Seibu Railway Co., Ltd.

1. Introduction

The project was to build an underground crossing under a railway while constructing a new building after the old one was torn down. High speed Element Pull and Jointed Element Structure (HEP & JES) construction methods was used in this non-drilling project under multiple railroads including signal sytems at one of the major terminal stations in Tokyo where around 490,000 travelers go in and out of. A launching shaft was established in the basement levels of the building under construction and the project was done simultaneously in an extremely small space under many severe conditions. The following will report on the challenges of constructing an underground crossing under the railway and the conditions of a launching shaft and arrival shaft, and the measures taken to resolve those challenges, as well as the results of the construction.

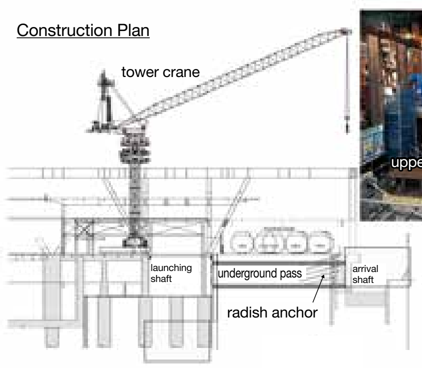

Photo 1 Launching Shaft (one leg portal crane)

2. Conditions of Construction and Challenges

There were five crossing railways, with about 650 trains coming and going in one day. As the site was a terminal station, there were a scissors crossing and other switches. The space is very small compared to usual shafts. The arrival point had a radish anchor for the earth retaining wall left from the previous construction.

3. Resolutions

(1)Drilling by Hand
Excavation was done by hand driller to repress any impact on track displacement while drilling. Any underground obstacles or radish anchors known to exist were taken away from inside the cutting edge, as it was impossible to remove. So machine drilling was not appropriate.
(2)Construction time
Upper floor and first level side wall elements were constructed after operation hours of the subway, to eliminate any impact to track displacement. The hours were from 1:00 to 4:00 am, after the last train went away and before the first train arrived. The second level side wall and lower floor elements were constructed through day and night, regardless of the train operation, as there would be little impact on track displacement by the drilling.
(3)Using Friction Cut Sheet while Drilling the Upper Floor Element
Friction cut sheet was used during the drilling of the upper floor element to repress horizontal displacement and reduce friction with the ground.
(4)Management of Tractive Force, etc.
Estimated tractive force by drilling area, which was calculated from the ground and other conditions, was set over against realtime tractive forces for management. The realtime tractive force came out around 70% during the actual drilling, and there were no instances to make an

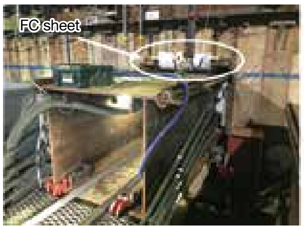

Photo 2 FC sheet (standard element 1080mm×850mm)

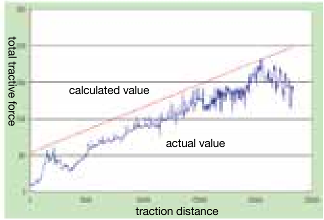

Fig. 1 Graph plotting the relevance of actual tractive force to distance (upper floor element)

emergency stop. (Fig.-1) The actuals are a result of using the friction cut sheet, the high precision of hand-drilling, the strong support from the natural ground consisting mainly of clay.
(5)Measuring Track Displacement
A measurement system (Digital Camera Rail Watcher) was used to measure track displacement all times during construction. Regular measurement was made as well. In addition to automatic tracking, level measurements and a 10m string was used to check the alignment of the tracks. These measurements were used to check the automatic tracking.
The trackings showed that the ground was gradually sinking (about 8mm), with no signs of rapid movement. Horizontal displacement was repressed by reducing friction between the upper side of the element using friction cut sheet. So the displacement was almost non (about 1-2mm), and with track maintenance the operations of the subway was not disturbed. There were no malfunctions of the signal systems during construction. Even though there was a small track displacement of 8mm, malfunctions were prevented during the construction with meticulous planning and measurements. Safety of train operation was ensured and the construction concluded as planned with no accidents and hazards.

Photo 3 launching shaft (lower floor element drilling)

Photo 4 Arrival shaft (drilling the side wall element)

4. Conclusion

The construction of the station building ended in spring 2019, and is now in business. I hope this report contributes in future non-drilling tunnel design and construction projects in urban areas.

References

Seibu Properties Inc. web site: http://www.seibupros.jp/about/develop/ikebukuro/Rail-ACT Research Group: HEP&JES Technical Material

Photo 5 Bird's eye view of DaiyaGate Ikebukuro (October 2018)

6

Overcoming Challenges: Small Overburden, Acidic Water, Construction Under a National Road

— The Yamagata Zao Tunnel, Tohoku Chuo Expressway —

Kazuo MIYAZAWA ▶ Vice President, Yamagata Construction Office, Tohoku Branch, East Nippon Expressway Co., Ltd.

Project overview

The Tohoku Chuo Expressway is an approximately 270km highway that connects Fukushima and Akita Prefectures. The Yamagata Zao Tunnel is an approximately 944-meter tunnel at the foot of the Yamagata Prefecture side of the Zao mountain range, famous for rime on trees. This tunnel has an overburden of 9.9 ~ 24.5 m and is almost entirely covered by small overburden of 1.5 D (D = 12.4 m) or less. Right above the tunnel cross a golf course, a river and a national road and near them are amusement parks and houses, so the impact of the tunnel excavation on those structures were concerned. The soil, composed of Quaternary mudflow sediments and Neogene tuff and tuff breccia, is, overall, less solidified and soft. Therefore, as the excavation system, the mechanical excavation was adopted, and as the main excavation method and auxiliary method, the full-face early closure and the injection type long steel pipe forepiling (AGF) were selected. The construction started in March 2016, and the tunnel was completed safely about one and a half years later, in September 2017.

Fig. 1 Conditions surrounding the tunnel

Boulders in the tunnel face

When the excavation of the mudflow sediment section started, boulders appeared in the tunnel face. The fall of large gravels may cause ground subsidence and cave-in, so as a countermeasure, the boulders at the top and side wall of the tunnel were sewn with lock bolts. AGF applied to the top was also very effective for sewing the boulders. Since many hard boulders could not be broken by a breaker, blasting was used each time.

Excavation under a river

We assumed influenced range under the 45° spread borderline from the river crossing as the range of influence, carried out the advanced horizontal boring of 113 m from the tunnel face and checked the soil quality and water quality condition. As a first step judgment based on the result, the possibility of drawing river water into the tunnel pit was judged to be low. As the second step, river water was analyzed according to the flood situation from the long steel pipe in AGF construction. The spring water from the long steel pipe was at most about 3 L/min per hole, which was stopped by grouting. Although the spring water from the cutting face was a little high (20 L/min), the tunnel face was stable enough and the river water was not drawn in and the tunnel passed safely under the river.

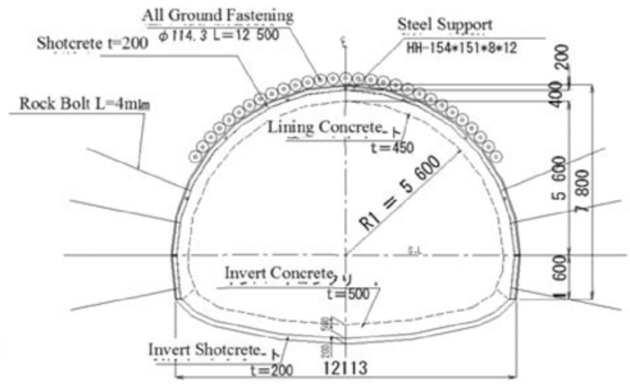

Fig. 2 Support pattern DⅢa-1-1-K

Construction under the national road

The point where the national road crosses has a small overburden of 12.5 m, and problems such as uneven ground were of concern, thus to improve the soil, chemicals were injected from the surface. The range of countermeasures for soil improvement was set as 18.4 m in width, 9.2 m in height, and 55.4 m in extension of the influenced range of 45° spred borderline from the edge of national road. Ultrafine blast furnace slag was used as the chemical, and the injection ratio was 24.0%. The pressure was set to 2.0 Mpa based on the test injection, but when the injection started, the surface uplift was larger than expected at the initial stage, so limited injection was applied instead, concentrating on fragile part. The countermeasure construction from the ground surface was complete when the injection quantity reached about 48% for the designed quantity. Also, the amount of land surface subsidence at the point where the national road crosses was constantly calculated by the total station. It turned out that the ground subsidence of maximum 14 mm was confirmed, but it was within expected level.

Tunnel Construction in a Widened Section

— The Kamiyagisawa Tunnel, Chubu Transversal Expressway —

Kiyohiko YUKITA ► Civil Engineering 1, Civil Engineering Division, Nagoya Branch,
TODA CORPORATION

1. Introduction

Kamiyagisawa Tunnel is on the Chubu Transversal Expressway (a national expressway that is 132km long). It is a two-lane, 678km-long tunnel that was planned for expansion in five phases for 130.5m from the exit side of the portal.
The largest expansion profile of this tunnel (226m^2) is approximately 2.2 times of the standard profile (103m^2), and has one of the largest tunnel profiles in Japan (Photo-1).
The profile of the expansion area had small overburden, and the base mudstone was weathered. Along with the thin layer of crush and intrusive rock, the area was weak in geological conditions. This report will detail on the countermeasures taken during the construction to stabilize the tunnel face and crown, as well as measures taken to increase safety during excavation.

Photo 1 Largest Excavation Section with size 226m^2

2. Stabilizing the Face

Long steel face bolts (ϕ 76.3mm, L=12.8m, wrap length 3.5m, 12 bolts/section, 6 shifts, silica resin 70kg/bolt) were implemented to stabilize the face of the expanded area. The long steel face bolts helped increase the shearing resistance of the face and restrain preceding displacement and dropout rock.

3. Three-Division Excavation and Excavation of Advancing Drift

Among the five phases of expansion, excavation of the top half of the expanded section of the third to fifth phases (L=76.5m) becomes higher than the boom type cutting machine. Advanced multiple bench cut method (Three-division was adopted. This method breaks up the excavation section, allowing the stress release to be smaller and the tunnel face stabilized.
The expansion section area from the fourth phase (L=46.5m) onwards needed the natural ground of the portal to be fortified in advance, since the overburden was small and the geological conditions weak. So, a pilot drift was penetrated in advance for the following purposes:
 Preceding fortifications of the upper half of the natural ground of the expansion section using the pilot drift's GFRP rock bolts (L=4m, ϕ 27mm, bearing 343kN, 6bolts/space)
Ensure the stability of the natural ground around the portal using long steel bolt fore piling from the portal after the drift had been penetratedAfter taking the above measures, the multiple bench cut method was used to excavate the largest expansion section area (Fig.1).
With combining the pilot drift with multiple bench cut method, the loosening of natural the ground around the expansion area was repressed, and stable excavation was possible.

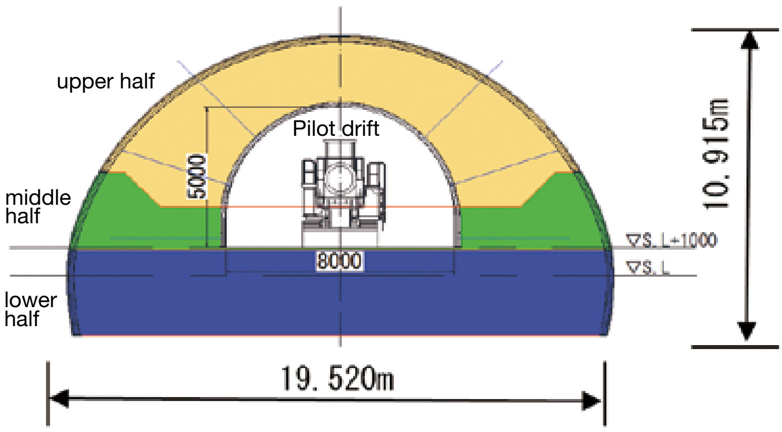

Fig. 1 Pilot Drift and Three division excavation

Construction Period Shortened with Precast Concrete for Mountain Tunnel Lining

— South Side Construction of Tarutoge Tunnel, Chubu Odan Expressway —

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Hiroyuki IDEURA ▸ Project Manager, Civil Engineering Dept., Nagoya Branch, SHIMIZU CORPORATION

1. Overview

The Tarutoge Tunnel is a mountain tunnel of Chubu Odan Expressway which constitutes the Honshu (main island) crossing route, and an evacuation tunnel runs along the main tunnel. Among the 2,621m evacuation tunnel of the south side construction section, 500m section was constructed by "PCL method," a lining method using the precast concrete panels (PCa panels). The construction started in June 2011 and ended in January 2019, and the service began from March 2019.

2. Why PCL Method Was Selected

In order to achieve the service commencement goal of the expressway, it was necessary to shorten the lining process of the evacuation tunnel, which was considered a bottleneck. If the construction was to be carried out by on-site casting, it would be necessary to simultaneously set 3 formworks in the evacuation tunnel, but its cross-section was small, which restricted carrying in and out any vehicles, and so simultaneous setting was impossible (Fig. 1). Due to recent shortage of engineers, it was also difficult to secure engineers who could construct lining concrete. Thus, the PCL method using the precast parts was adopted because it enables simultaneous construction with on-site casting even in the tunnel with small cross-section. Also, the method ensures a certain level of quality without having highly skilled engineers on site.

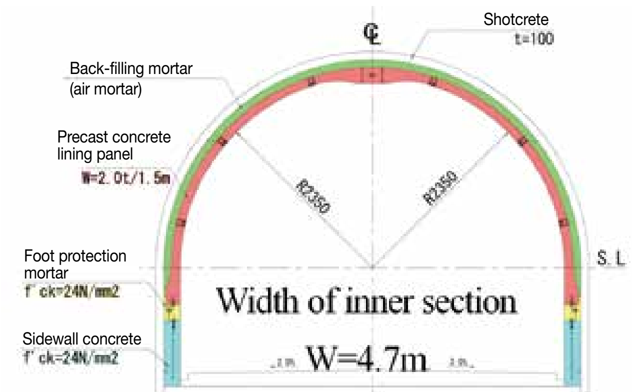

Fig. 1 Cross-section view of the evacuation tunnel

3. Characteristics of The PCL Method

PCL method is for interior work, finishing, repair or reinforcement of a tunnel. It is a lining method in which arc-shaped PCa plates divided in two in the tunnel transverse direction are installed on side walls constructed beforehand. PCa plates used in this method are made in a factory, ensuring high quality. Their high stability is realized by backfilling between PCa plates and the bedrock. The process shortening is possible by adopting the mechanized construction with special machines, not requiring highly skilled engineers.

4. Construction Report

The construction was divided into three steps: (1) preparatory work, (2) installation of PCa panels, and (3) mortar casting. First, the sidewall concrete is constructed by on-site casting. Secondly, with the sidewall as a base, PCa panels divided into 2 parts are installed on top, in 20 minutes per piece (Fig. 2). Finally, the void between the PCa panels and the side wall, and between the panels and the bedrock were filled with mortar. The first and third steps were carried out concurrently with other works.

By adopting the PCL method, material cost increased, but the target process was secured with reduction of the number of workers for placing. Since the plates were factory-made, the risk of problems such as filling failure of concrete was reduced, and the surface finishing was very fine (Fig. 3). It is expected that PCa will be considered as an option of the design and construction method for mountain tunnel lining with various constraints.

Fig. 2 Construction in progress

Fig. 3 Construction in progress

Excavating Mixed Rock, where Risk of Landslide is High

—South Construction Site of Yoshinomoto Tunnel, Higashikyushu Expressway—

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1. Introduction

The Higashikyushu Expressway is 436km long, with Yoshinomoto Tunnel being 1,880.0m of it. Soil of the area surrounding the tunnel is weak, consisting of disorderly mixed layers of psammite and shale. There were many cases nearby tunnel constructions had difficulty excavating. This tunnel was first planned to be excavated only from the northern entrance, but tunnel support was deformed by natural ground load larger than expected. It took extra time to consider measures to prevent landslides and other issues. In the end, excavation of the tunnel was done from the southern entrance too, for 581.4m of the whole 1880.0m length.

2. Supporting Structure

Excessive natural ground load at the north site made the rigidity of the tunnel support insufficient. Fig. 1 shows the deformation made at the connection point of the invert strut. Data collected from the north site was analyzed and used to re-design the supporting structure of the south. The basic strategy was to allow early closure (Total spray thickness t=250mm, invert strut H-200 along the whole perimeter) and make the cross-section of the invert closer to circular shape than usual. This reduced the concentration of stress in corners and increased the rigidity of the tunnel support (Fig. 2).

Fig. 1 Deformation

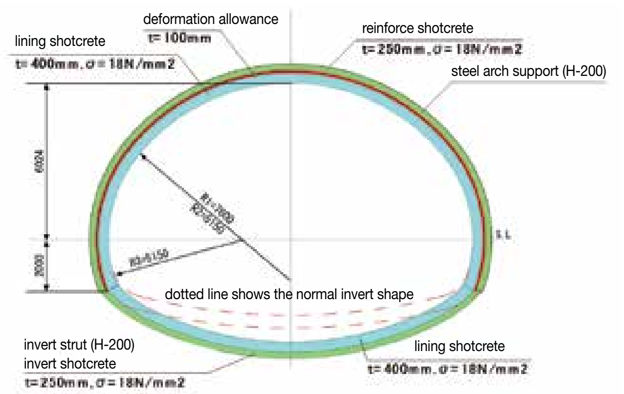

Fig. 2 Support Structure

3. Construction Work to Prevent Landslides

Active landslides were found at the portal of the south site. The tunnel was under the landslide surface (Fig. 3). The method chosen was "counterweight fill works". During the excavation, long steel pipe forepilling and long face reinforcing were used to minimize loosening of natural ground as much as possible. After the banking was made, the central heading was dug before the main tunnel, for geological survey and monitoring of landslide behavior, as in Fig. 4.

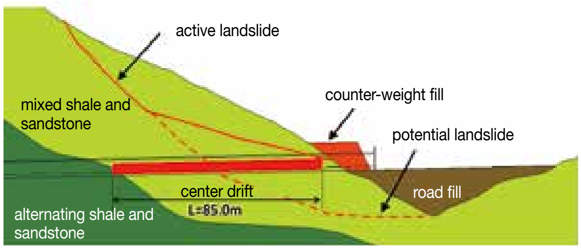

Fig. 3 Geological Profile of South Site Portal

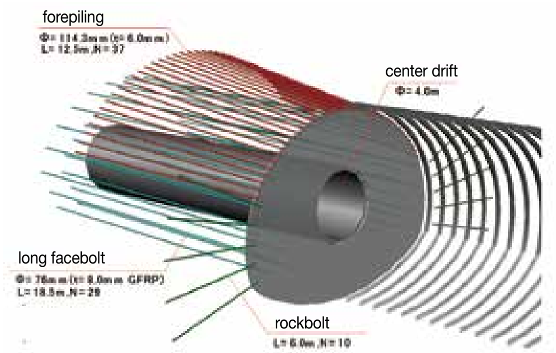

Fig. 4 Summary of Countermeasures to Prevent Landslides

4. 3-D Modeling of Field Observation of Landslide

Ground surface was measured to observe behavior of landslides. Ground surface changes were judged whether they were 1) direct deformation of the ground due to excavation, or 2) could cause active landslides. 3-D models were made from the measurements to determine detailed movement of the whole ground soil for the progress of the tunnel works (Fig. 5). This model showed that no landslides were caused. The excavation was finished safely.

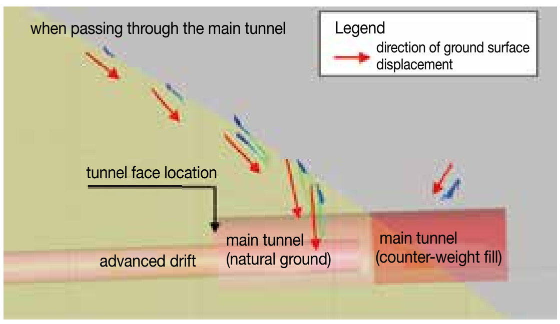

Fig. 5 3-D Modeling of Measurements

Verification of Deformation During Excavation of Pelitic Schist and Effect of Countermeasures

— The Matsukaya Tunnel on National Highway Route 197 —

Takeshi YAMAUCHI ▶Manager, Ozu-Yawatahama Expressway Construction Division,
Yawatahama Civil Engineering Office, Nanyo Regional Bureau, Ehime Prefecture

Introduction

The Matsukaya Tunnel is a two-lane road tunnel with a total length of 1,090meters. The soil consists mainly of fragile pelitic schist. During the excavation, maximum horizontal displacement of 770mm in one side occurred, along with significant deformation of the primary support including cracks in shotcrete, fractures of rock bolts and buckling of steel support, in addition to cracks and heaving of invert concrete.

This paper describes the construction results in fragile pelitic schist and countermeasures against the risk of deformation developed in the tunnels in service. It also reports the verification results through numerical analysis of the mechanism of deformation and the effectiveness of countermeasures.

1. Excavation Situation

During the excavation of pelitic schist, damage and extrusion of the primary support occurred frequently (Photo 1).
To secure the soundness of the primary support and the necessary inner space, the primary support had to be repeatedly rebuilt. After the excavation, the invert was closed early to control the displacement and stabilize the tunnel. However, the earth pressure increased with time even after the invert was closed, and the steel support buckled (Photo 2). In addition, damage and heaving of the invert concrete were recognized, and tunnel was considered at risk of deformation after the start of service.

Photo 1 Extrusion of primary support

Photo 2 Buckling of steel support

2. Countermeasures Against Deformation

To stabilize the tunnel during construction, the thickness of shotcrete was upgraded from 15cm to 20cm, and the steel support from H-125 to H-150.
To cope with the risk of tunnel deformation after the start of service, the invert was reinforced with invert struts as shown in Figure 1, and non-steel fiber was mixed in the lining concrete to prevent flaking.
In addition, for the purpose of confirming stability of tunnel in service and detecting signs of deformation early, stress measurement and convergence measurement of lining and invert concrete were planned, and they were carried out from the start of construction.

3. Verification Through Analysis

To simulate the phenomenon at the time of excavation and to verify the effect of countermeasures, numerical analysis with the following features was carried out.

- From the linear elastic analysis of the wide area model, the initial stress state of the tunnel's surrounding bedrock is obtained (Figure 2).

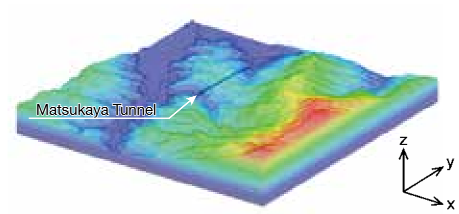

Fig. 2 Wide area terrain model

- The degradation model was based on the Mohr-Coulomb yield criterion, and the strength decreased with time after plasticity.

As a result, the following phenomenon were simulated: (1) at the time of excavation, large displacement occurred in the mode in which horizontal displacement was dominant, (2) primary support was damaged again after invert closure, and (3) invert was heaved. In addition, this model proved that the future stability of the tunnel is ensured even if the ground strength was further reduced, confirming the effectiveness of the countermeasures (Figure 3).

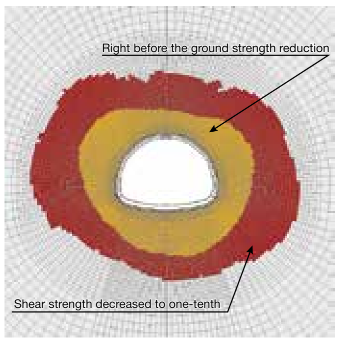

Fig. 3 Change in plastic zone due to bedrock degradation

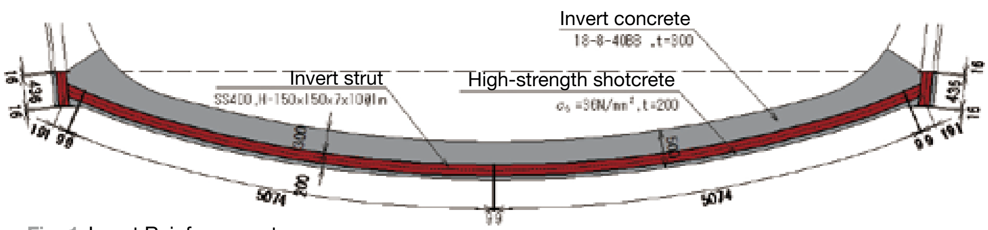

Fig. 1 Invert Reinforcement

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Drilling and Blasting Hard Ground Close to Rocks in Danger of Falling and a Railway Tunnel

— The Shin-Udomari Tunnel, National Highway Route, 345 —

Yousuke KUBOTA ▶ Chief, Road Section, Regional Development Department, Niigata Prefecture Murakami Region Promotion Bureau

Yasumoto OGAWA ▶ Site Manager, Shin Udomari Tunnel Construction Site, Niigata Head Office, Fukuda Corporation

Kazuhito WAKATSUKI ▶ Manager, Civil Engineering & Technology Planning Dept., Fukuda Corporation

1. Introduction

The Shin-Udomari Tunnel is built on a steep slope where rocks in danger of falling are spotted. The tunnel site is on the National Route No. 345, and near a railway tunnel that is being used today, 90 years after its construction (Fig. 1 & Fig. 2). The plan was to use blasting excavation method, which required strict management of the blast vibration, along with protecting the safe operation of the railway and the national route. However, a granite layer from Cretaceous, the last period of Mesozoic was found, which was extremely hard with virtually no cracks. This reduced the possibility of reducing the blast vibration that would reverberate within the natural ground, thus making any counter measure difficult to implement. This report introduces the rock breaking and controlled blasting methods used to reduce any impact on the railway tunnel and national route.

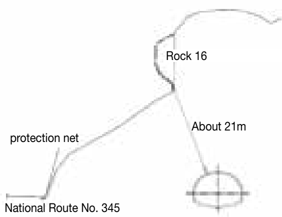

Fig. 1 Location of Rock in Danger of Falling 16

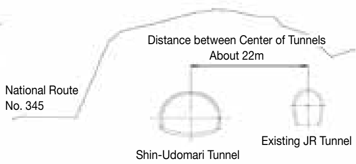

Fig. 2 Cross-section of Existing Railway Tunnel at its Nearest Point

2. Dealing with Rocks in Danger of Falling

Rocks right above the national route had most potential impact when they fell near the portal. Construction work would be done near the risky rocks from the start of excavation. Standard management value of the blast vibrations was set to 0.5cm/sec, after consulting earthquake data and actual data from similar construction works in the past.

Initially, the objective was to use machine excavation as much as possible, with pilot blasts conducted to plan controlled blasts that would clear the management standard values and move onto blasting. However, a firm granite layer with a small number of cracks was dug up just after excavation started. This made machine excavation and blasting within the management standard values of blast vibrations difficult. Rock breaking method to machine excavate hard ground without blasting was adopted (Fig. 3 & Photo 1). This tunnel was excavated using a 3,000kg-class breaker after fixing the free face inside and surrounding the cutting face.

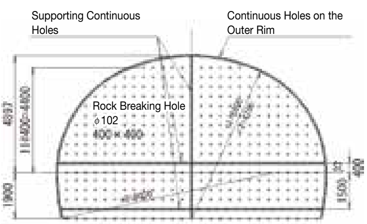

Fig. 3 Standard Pattern of Breaking Rocks

Photo 1
Work of Continuous Holes and Rock Breaking Hole

Other rocks were deemed less disaster risk considering the location of the rocks and the national route. Risk reduction measures were taken after rock falling simulation results were obtained (Fig. 4). Multi-staged controlled blasting that cleared the standard management values was conducted.

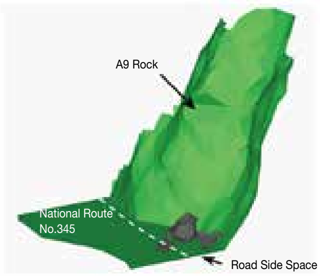

Fig. 4 Results of Rock Fall Simulation

3. Measures regarding Railway

Control value of the blast vibrations was set to 2.5cm/sec. after due consultation with the railway management. Initial design adopted a multi-staged blast using the Double V cut method along with DS+MS detonator. With this detonator creating more vibrations than expected, a detonator with fuse tube was used to coordinate a multi-stage blasting, one stage per one hole (Fig. 5). The forecast formula of blast vibrations was constantly updated during excavation, so the construction would continue while predicting the impact of the blasts.

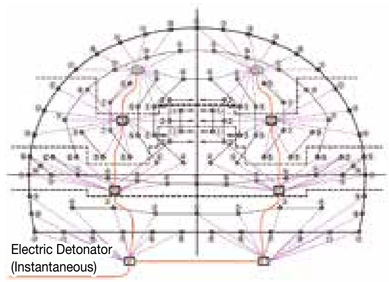

Fig. 5 Controlled Blasting using a Detonator with a Fuse Tube

4. Conclusion

Though the conditions of the nearby constructions and natural ground were severe, the tunnel excavation was completed while minimizing impact from the rocks in risk of falling, and towards the existing railway tunnel. Results are as below:

Section where rocks were near: Vibration speed of the rocks during breaking were predominantly 0.01cm/sec. or smaller. This was about 1/20 of the blast vibrations of the controlled blasts conducted in sections after this one. The tunnel was excavated safely with no rocks falling.

Section where railway was near: Vibration speed of the inner wall of the existing tunnel was under the management standard value during multi-staged controlled blasting. Impact on the existing railway tunnel and railway operations were minimized.

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Tunnel Construction Directly Beneath a Residential Area

— The Yasumiyama Tunnel, Nagasako, National Highway Route 185 —

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Katsumasa KURATA ▸ Manager, Civil Engineering Department, West Japan branch, Okumura Corporation

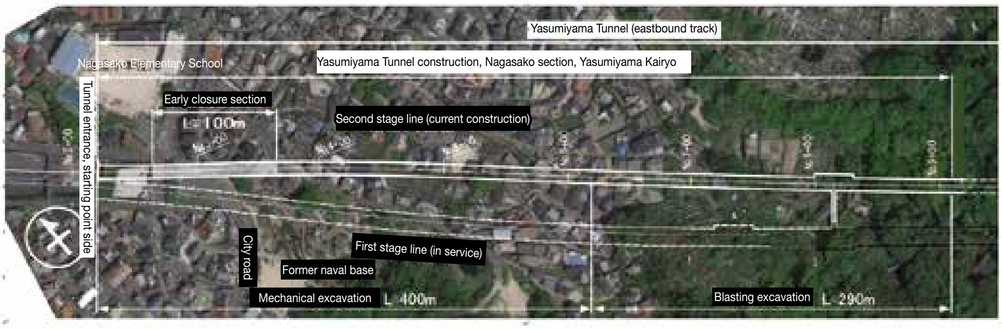

Fig. 1 Top view of the construction, Yasumiyama Tunnel, Nagasako section

Introduction

The Yasumiyama Tunnel construction in Nagasako section of Yasumiyama Kairyo is to double the lane of "Yasumiyama New Road, Highway National Route 185," located in the central part of Kure City, Hiroshima Prefecture. Right above the Nagasako section are lifelines buried in the city road, dense residential area etc., and the 1st stage line tunnel in service runs parallel to it at the distance of 1 to 38 m (Fig. 1). Thus, challenges were to reduce bedrock loosening due to excavation and the ground surface subsidence due to consolidation subsidence accompanied with groundwater drainage, and to control propagation of vibration and noise to the surrounding area. This paper introduces the measures and results in meeting the challenges.

1. Subsidence Control by Early Closure

The 140 m section from the tunnel entrance is covered with overburden of less than 30 m and the ground is composed of weak, weathered granite of DL to DH grade. Thus, early closure using steel invert as well as tunnel crown and face stabilization measures by injection-type long steel pipe forepiling and injection-type long mirror reinforcement were carried out at every 1m-excavation within 5m-separation from upper half face. The behavior of the city road etc. right above the tunnel was controlled by the continuous measurement by the automatic tracking type total station and the subsidence measurement using the SAR satellite which can grasp the extent of the surface subsidence area. Fig. 2 shows the subsidence measurement result of the city road located just above a tunnel. It shows that about 20% of the total subsidence is generated as a preceding displacement before reaching the upper half face, and when the upper half face reaches 1D (≒ 10 m) from the right under the city road, the displacement tends to converge. The largest subsidence was 14 mm, almost equivalent to the prior analysis result.

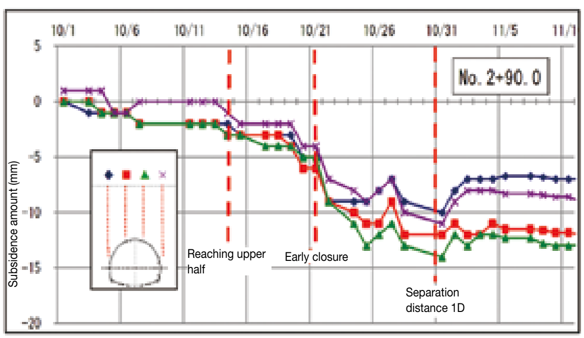

Fig. 2 City road surface subsidence measured

Blast specifications

Distance from the blasting position	87.3m	Gunpowder amount per hole	0.63kg
Total amount of gunpowder used	51.4kg	Detonator used	eDevII detonato
Total number of holes	82 holes	Vibration velocity(Max)	0.056Kine

Fig. 3 Vibration waveform right above the tunnel, controlled blasting

2. Blasting Vibration Control with Special Electron Detonator

At the 400 m point from the tunnel entrance where hard rock was found, controlled blasting (gunpowder less than 0.8 kg/hole) of one hole per stage using the special electron detonator eDevII was adopted to reduce the vibration effect to the residence above the tunnel and the parallel 1st stage line tunnel. eDevII is excellent in detonation accuracy, and detonation timing can be freely set on site in milliseconds. On site, the blast delay time was set at 8 ~ 15 ms, and the optimum time difference was selected by feeding back the measured values to the setting. Fig. 3 shows the blast specifications and the vibration waveform in the vicinity of the residential area right above the face. It shows that the vibration speed was suppressed to the control target value of 0.07kine or less at the measurement point right above the face, and that the vibration time was controlled accurately to about 1.0 seconds, which is almost unrecognizable by the human senses.

Conclusion

The ground deformation, vibration and noise due to the ground loosening, etc. were concerned, but the construction was completed without huge negative effects to the surrounding environment.

Construction of Adjacent Tunnels Using the URUP Method

— Tate First Tunnel, Hachioji South Bypass —

Masataka HAYASHI ▸ Construction Manager, OBAYASHI CORPORATION

Introduction

The Hachioji South Bypass of National Route 20, currently under construction, is 9.6 km long, and near its center are tunnel structures of about 0.5 km. Initially, cut and cover method was planned for the tunnels, but since the area became increasingly residential with a compact cluster of houses, shield method was adopted to lessen the effects on the surrounding.
Several roads cross over the tunnels which have small overburden. Thus, a safe and reliable construction method was needed to minimize the effects on road surfaces, road attachment (such as retaining walls) and surrounding houses. Also, the distance between the two tunnels to be constructed was small and it was necessary to prevent the construction load of the following tunnel from affecting the lining of the preceding one.

1. URUP Method Adopted

In this construction, "URUP method (Ultra Rapid Under Pass Method)" was applied, in which the shield machine start excavation from the ground level without constructing a vertical shaft. Fig. 1 shows a plane view and longitudinal section view of the area. The shield machine begins excavation from the work yard of the launch side, proceeds on the outbound line, makes a U-turn at the purpose-built vertical shaft and excavates the inbound line next to the outbound one.
At the position immediately after the machine start excavation, there were two roads crossing aboveground, and the minimum overburden is 2.6 m. Since there was no vertical shaft, the machine started excavation with all necessary equipment set behind it on the ground (Fig. 2). Therefore, right after the launch, the machine was able to pass under the crossing roads without any changeover, which is usually needed during the initial excavation by a shield machine.
By passing under the roads quickly without stopping for changeover, the effect on the roads was minimized.

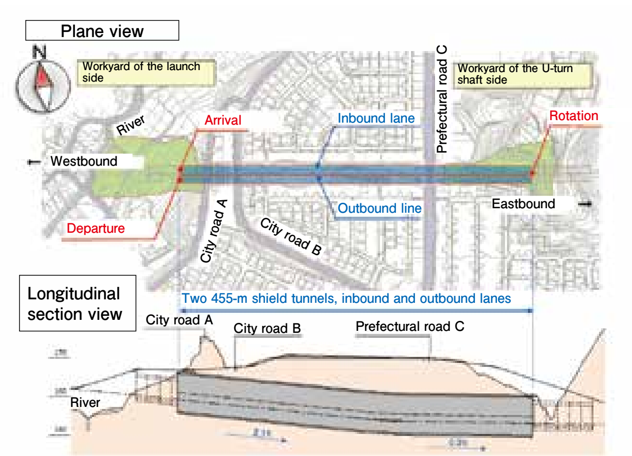

Fig. 1 Plane view, longitudinal section view

Fig. 2 Equipment set and launching at ground level

2. Measures for Adjacent Tunnels

The distance between the two tunnels was as small as 0.9 m, and it was crucial to secure the soundness of the preceding tunnel lining against partial loads such as tunnel face pressure and backfill grouting pressure caused by the adjacent construction of the following tunnel. Thus, the internal support was installed in the preceding tunnel based on the prior analysis (Fig. 3). The support was of the bogie type, and the lining in the affected area was supported by moving the position in accordance with the progress of the following tunnel. As a result of these measures, the excavation of the adjacent tunnels was completed in eleven months without any problems and the tunnels reached aboveground (Fig. 4).

Fig. 3 Bogie-type internal support

Fig. 4 A tunnel reaching aboveground

Excavating the Shield Tunnels with the Largest Cross Section in Japan

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Kenji KATO ► General Manager, Tokyo-Gaikan Construction Office, Kanto Regional Head Office, East Nippon Expressway Co., Ltd.

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

Introduction

Tokyo Outer Ring Road (Kan-Etsu-Tomei) is the first expressway project in Japan to fully utilize the great-depth underground area. The total length is approximately 16.2 km, and the two main tunnels with three lanes each side are to be constructed by the shield machines of about 16 m diameter, the largest cross section in Japan.
Since the construction conditions are tough — large cross section, long distance and high speed — the excavation started from both the north and south sides of the tunnels, to extend the drilling distance as long as possible to prepare for the failure of shield machine. Of the two tunnels, Central Nippon Expressway Co., Ltd., is responsible for the north-bound and East Nippon Expressway Co., Ltd. for the south-bound. Each divided the tunnels into two parts (starting from north / south) and ordered the construction to builders. Thus, four shield machines are now in operation. This paper introduces the features of the machines of the north side and the current state of the construction.

1. Characteristics of The Machines

The shield machines, equipped with single-pressure method long jacks, simultaneously excavate the tunnels and assemble the segments to speed up the construction and prevent the segments from being damaged by eccentric load.
To dig through underground obstacles in the shallow depth of the north side, the machines have following features:
The northbound machine is equipped with a slanting cutter head and special reinforcing type preceding bits (Fig. 1).
The head with a 5 ° angle slant enables intermittent cutting, reducing the load when cutting through obstacles. The bits are fan-shaped for excellent resistance against abrasion and shock, enabling direct drilling through obstacles and long-distance excavation without exchanging bits.

Fig. 1 Northbound shield machine

The southbound machine is also equipped with a slanted cutter head (5°) as well as with the "long-life bits" (Fig. 2), designed to protect super-hard chips of high wear resistance with high impact-resistant chips, enabling long distance excavation without exchanging bits.

Fig. 2 Southbound shield machine

Moreover, for the northbound machine, three screw conveyors are arranged in series (approx. 50 m) as well as three barrier gates to reduce the risk of spouting the earth and sand, etc. For the southbound machine, two screw conveyors (approx. 40 m) are arranged independently to improve water resistance and prevent the halt of excavation.

2. Current State of The Construction

On the north side, the tunnel's starting shaft has been constructed, the machine assembly completed, and the initial excavation began from Jan. 2019. (Fig. 3). The drilling on the southern side started earlier on Feb. 2017 and as of Sept. 2019, the total excavated length is about 1.9 km.

Fig. 3 Oizumi JCT, Feb. 2019

The drilling will be carried out with the highest priority on safety, while confirming the volume of excavated soil — using a belt scale for the weight and a laser scanner for the volume — and conducting monitoring such as measurements of underground and ground surface.

Construction of Large Section Shield Tunnel at a Location with Sharp Curve, Steep Slope, and Adjacent to Important Structures

— Baba Ramps of Kanagawa Route No.7 Yokohama North Line of Metropolitan Expressway —

Masayoshi SATO ▸ Deputy Manager, Design Division,Kanagawa Construction Bureau, Metropolitan Expressway Co. Ltd.

Baba Ramps is found at around the middle of Kanagawa Route No.7 Yokohama North Line of Metropolitan Expressway, which opened in March 2017. There are four ramps connecting the main tunnel to the streets on the ground level, and a large part of ramps is tunnel structure. The area near Baba Ramps is a heavily populated residential area, with the main tunnel connecting at a great depth with overburden of 31-51m. This is the reason why TBM was used. The four shield tunnels were constructed from two launching shafts build within the site and connected to the main tunnels' underground enlargement, which was constructed using the piperoof method when the Expressway was built.

1. Features of the Baba Ramps Tunnel

The four ramp tunnels' diameters were set at the minimum with consideration to construction gauge, evacuation routes, inner section conditions and curve widenings.Large section shield machines with outer diameters of ϕ 10.13m - 11.13m were used. The B ramp tunnel had a sharp curve (minimum curve radius 50m) and steep slope (maximum grade 7.6%), measures were taken to control the position of the shield machine while excavation. Also, the shield machine excavated through an overburden of minimum 1.3m, so measures were taken to prevent the segments from rising.

Construction of ramp tunnels have excavations with small overburden right below streets and residential areas. The ground under residential areas consisted of alluvial cohesive soil layer with humus soil. A pilot excavation was done within the site right after the shield launch to preset the excavation management values.

2. Excavation Near Important Structures

There was a transmission tower 15m ahead of the start of the D ramp tunnel, with the minimum separation to the tower foundations being 4.7m (0.48D). Effects of excavation to the tower was assessed, and the tower foundations were reinforced to restrain changes of the tower. Measurement control and excavation management values of the tower base were set along with measures to prevent loosenes of natural ground during construction.

The A ramp tunnel was constructed near to the main tunnel, with the minimum distance 1.2m. Construction had to be finished without affecting the main tunnel, which was in use at the time. Construction data obtained from the three ramp tunnels excavated before the A ramp tunnel was used to preset excavation management values, and the main tunnel's real time measurements and inspections were conducted. The shield machine was dismantled after taking safety measures by protecting the vehicles going through the main tunnel with a temporary wall built up beforehand. The temporary wall was taken out after the A ramp tunnel's excavation was finished.

3. Conclusion

With adequate measures taken, any influence of the construction to houses on the ground and important structures such as the transmission tower and main tunnel (which was in service) nearby were reduced, and the four-ramp tunnel was completed safely.

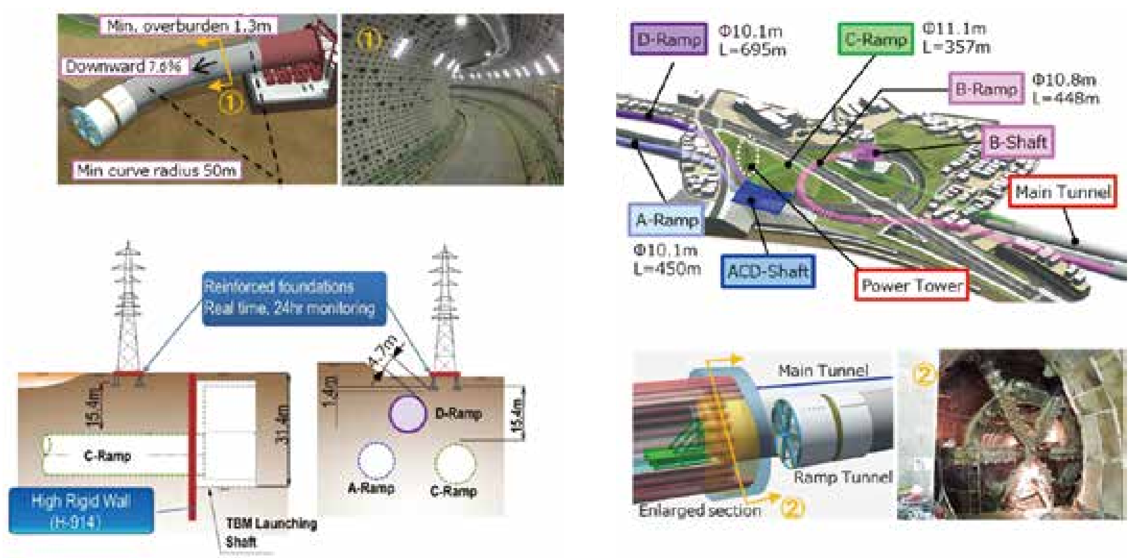

Fig. Features of the Baba Ramps Tunnel

High-Speed Construction with Large Section Slurry Shield Method

— Kanagawa Route No.7 Yokohama Northwest Line of Metropolitan Expressway —

Katsuki IRINO ▶ Manager for Yokohama Ring Expressway North-West Line Construction Division, Road and Highway Bureau,City of Yokohama

Masanobu NAGAI ▶ Deputy Manager, Design Division, Kanagawa Construction Bureau, Metropolitan Expressway Co., Ltd.

Yokohama Ring Expressway North-West Line is an car-only, 7.1km-long expressway (including a tunnel area about 4.1km) that runs through the northwest region of Yokohama City, Kanagawa Prefecture. The two shield tunnels (inner diameter 11.5m, outer diameter 12.4m, segment width 2m) partially runs under railways and rivers with a maximum overburden of 67m, and the length of excavation was about 3.9km. As the total produced earth was 1.16 million m3, slurry shield method was adopted for stable disposal. The following technical measures were taken to quickly complete the project, especially to increase the speed of shield tunnel construction.

1. Technical Measures Taken to Increase Construction Speed

1) Simultaneous Excavation and Assembly of Segment

Among the four steps, namely: 1) preparation, 2) excavation 3) segment assembly, and 4) pipe extension, standard construction time per ring was reduced 20% by conducting parts of 2) and 3) simultaneously. Assembly time per ring was reduced also by increasing the turning speed of the erector and the excavation speed.

2) Increasing Pumps, Muddy Water Treatment and Facilities to Carry Out the Soil

The number of sludge discharge pumps was increased to two from the usual one on the succeeding cars, which increased transport capacity. Also, the initial and secondary treatment filter presses were added to take out soil that was beyond expectation (for example, soil of 100% sand or clay), so the maximum excavation amount planned (24m per day) could be actually conducted. The soil pit capacity was increased to 1.5 times more than usual, so the excavation could be done at times when the discharge could not be carried out. This resulted in increased number of working days.

3) Stable Treatment of Produced Earth

With increased excavation speed, the amount of produced earth also increased up to 7,000m^3 per day at maximum. The soil was reused widely between the construction sites, and construction sludge was recycled after administrative procedures. Twenty sites were found to carry out the soil and construction sludge, which ensured steady treatment of produced earth.

4) (MSV) Multi-Service Vehicles

Multi-Service Vehicle (MSV)s were used to transport segments inside the tunnel. This eliminated the need to build a railway for the conventional vehicles used for shield tunnel constructions. This also helped in quickly starting the next phase of construction. MSVs were also proven as a safe transport device when running through longitudinal slopes of maximum 5%.

Photo 1 (MSV) Multi-Service Vehicles running on Tires

5) Using Composite Segments

Parts of open-cut from the shield tunnel and low overburden parts (areas under ventilation devices) are especially loaded parts, which need segments with high rigidity. This project reduced the step of adding a refractory panel by using a "composite segment with steel and concrete mixed with organic short fiber" instead of attaching refractory panels to steel segments.

6) Using Precast Products

Precast products of inverts and floor slabs were used to ensure quality management and reduce construction work. These contributed in avoiding the risk of delay in construction.

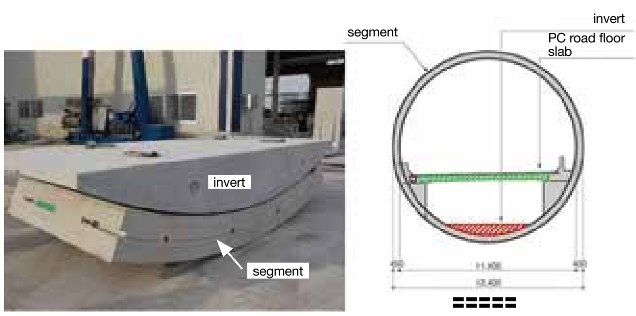

Fig. 1 sectional plan in one of two shield tunnels

2. Conclusion

With this Large Section Slurry Shield Method Construction, high-speed excavation was established at a maximum of 450m per month. The excavation of approximately 3.9km was completed in about an year and a half.

Photo 2 Arrival of the Shield

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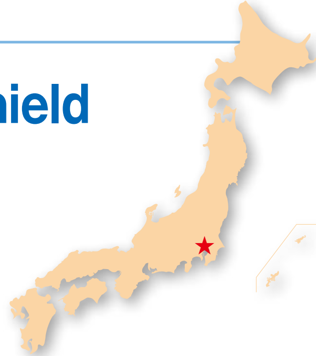
World's First Spiral Excavation Using H & V Shield Method

— Construction of Rainwater Discharge Pipe under Tachiaigawa River —

Hiroyoshi OHTA ▸ Construction Manager, Tokyo Civil Engineering Branch, SHIMIZU CORPORATION

Ryunosuke KASHIMA ▸ Manager, Civil Engineering Technology Division, SHIMIZU CORPORATION



1. Introduction

In this project, two sewer culverts with inner diameter of 5 meters each were constructed right under the Tachiaigawa River in Shinagawa Ward, Tokyo, to reduce flood damage and improve water quality.

Due to the narrow river width and existing underground structures, the tunnel alignment was horizontally and vertically restricted, thus the spiral excavation by H&V (Horizontal & Vertical variation) shield method was used (Fig. 1.). The H&V shield tunneling method, developed to construct a wide variety of tunnels depending on the tunnels' location and intended use, enables simultaneous excavation of two very close circular tunnels, twisted routes (spiraling) and single circular tunnels branching from a dual one.

The project was the first in the world to carry out spiral excavation in actual construction.

2. Spiral Drilling Section

Starting with the two shield machines connected side by side, the right-side shield was spiraled by 90° around the left-side shield in approximately 137-meter section. As the spiraling proceeds, each shield machine drills through the ground of different depths and geology.

3. Drilling Maintenance and The Result

In order to maintain a linear shape in a spiral drilling, the drilling must be carried out while maintaining a constant rolling amount. For this reason, linear control was carried out with an emphasis on attitude control of the machine such as maintenance of the swing angle (angle difference between rear bodies of right and left machines). In the spiral excavation, the results of the prior analysis by the H&V shield simulator were used as the initial values of the machine operation. During the excavation, the position and attitude of the machine and the behavior of the joint were grasped, and machine operations such as selection of jacks, thrust, extra excavation and articulation were carried out on a real- time basis.

As a result, the spiral excavation was finished within the linear control value without any trouble such as damage of the joint.

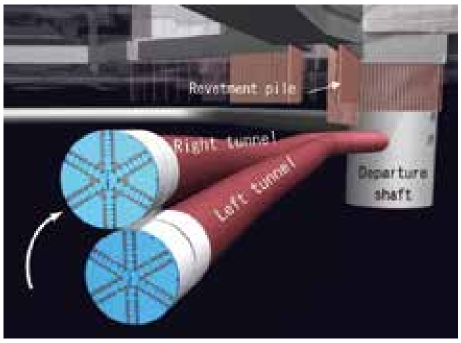


Fig. 1 Image of spiral drilling section

Fig. 2 H&V shield machines

Fig. 3 H&V shield machines in vertical shaft

Fig. 4 Inside photo of the spiral drilling section

PHOTO: Kenichi Komeiji

Diverging the Slurry Shield Machine from The Narrow Shield Yard

Katsutoshi KAWAI ▸ Chief, Construction Div., Technical Headquarters,
Nagoya City Waterworks and Sewerage Bureau,

1. Overview

Nagoya City has implemented the "Emergency Rainwater Drainage Project" to improve the level of facilities to deal with rainfall of 60 mm/h in principle, in areas where urban functions are packed and where severe flood damage concentrated at the time of Tokai Heavy Rain in 2000 and the torrential rain at the end of August, 2008.
As a part of the project, the construction of the bypass pipe (inner diameter 1,500 mm, approx. 850 meters long, overburden 4.0 m to 6.5 m) was carried out in the Hojin, Minato Ward, located in the southwest of Nagoya City. (Fig. 1. Construction Outline)
For the tunnel excavation, the mini-shield tunneling method (outside excavation diameter: 1,950 mm) with small excavation cross-section was adopted because it was a field-proven method for the construction of sharp curved line up to 10 R, and the separation distance from the existing sewer pipe could not be secured with the ordinary shield tunneling method (outside excavation diameter: 2,280 mm).
This paper introduces the technical contrivance of the design and construction of the mini- shield method used beneath the highway in the urban area.

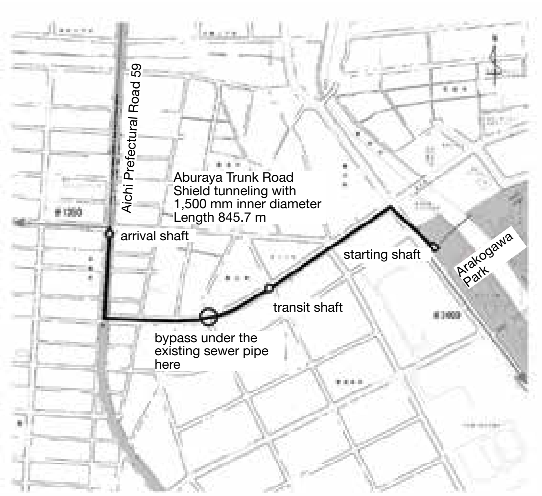


Fig. 1 Overview of Construction

2. Design

For the bypass pipe, the route under the existing sewer pipe (θ 1,100 mm) was selected, because there will be no influence on underground facilities of other enterprises and the sharp curved construction for changing the occupied positions were unnecessary.
The separation from the existing sewer pipe (θ 1,100 mm) was only about 20 cm, but to reduce any influences on the existing pipe, it was protected by the chemical grouting method.

3. Construction

A shield machine equipped with a gyrocompass and a level detector was used, since the distance from the existing sewer pipe is small and the construction with high accuracy was required due to the presence of many underground facilities.
As a result, the maximum deviation from the designed value at the center line was + 20 mm, which was within the range of ± 25 mm, the standard value of the authorities.

In advancing the construction, CIM data was created on underground facilities in the whole construction section. (Fig. 2 CIM Data)
The CIM data, which visualized the positions of the underground facilities in 3D, enabled all workers to grasp the positions and to confirm the separation between the shield machine and the existing sewage pipe and the underground facilities.
The chemical grouting as an auxiliary method for soil improvement was conducted without affecting the underground facilities, since the confirmation of drilling positions and separation was made easy with the data.

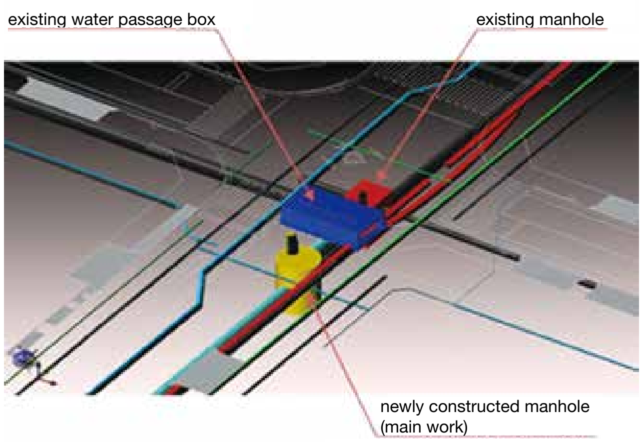


Fig. 2 CIM Data (Example)

Simultaneous Installation of Two Caissons

— Caisson Work at the Senjusekiya Pumping Station —

Ichiro KOYAMA ► Construction Manager, Senju Sekiya JV Project Office, Tokyo Main Office, OBAYASHI CORPORATION,

Takayuki SHIMIZU ► First Section Manager, The 1st Core Facility Reconstruction Office, Bureau of Sewerage Tokyo Metropolitan Government

1. Introduction

Senjusekiya Pumping Station located at the north-east of Tokyo, is a rainwater pumping station designed to cope with the increased rain runoff due to the recent climb of localized heavy rains.

Fig. 1

2. Outline of Construction

This was the first project in the world to simultaneously install two large pneumatic caissons for more than 50 meters underground. The two caissons, namely the west caisson (2,614m^2) and the east caisson (2,289m^2) were only apart for a distance of 2.0m.

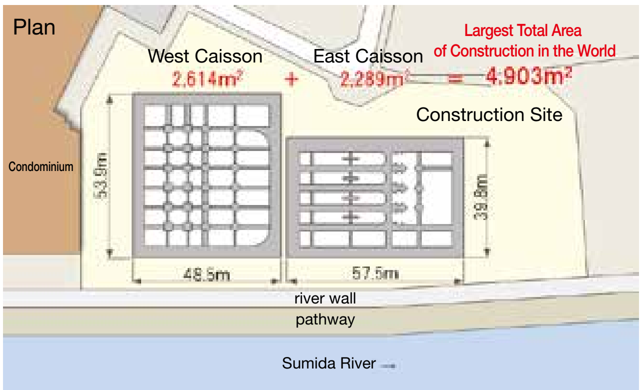


Fig. 2

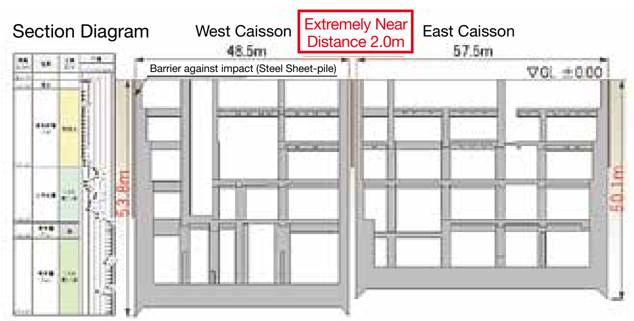


Fig. 3

3. Features of Construction

As this was an urban project, there were restrictions on the usage of land, which in place required to install the caissons in great depth. Also, the construction period had to be as short as possible, considering the burden causing to those living nearby. Pneumatic Caisson method was the resolution for these challenges.

The ground surrounding the pumping station is not rectangular, but heterotypic. Heterotypic caissons might get twisted, or have other problems when installed underground, so the two separate caissons were designed, as the drilling area had become larger than any similar project before.

4. Technical Issues and Resolutions Regarding the Two Caissons

Ground pressure and surface friction increased between the walls of the two caissons, as the soil changed from soft cohesive soil to over-consolidated cohesive soil, and then to gravel and sand layers. It was anticipated that the repeated shearing while installing the caissons had caused the volume of the ground to expand (positive dilatancy). The Drucker-Prager fracture criterion (a nonlinear dynamics model considering the dilatancy of the ground) was adopted to conduct a reproductive analysis of ground pressure. This revealed the fact that the dilatancy was larger than expected due to various factors: fast shearing speed during installation of caissons, adjacent face being wide (about 40m x 50m) and near (2m), and the ground being rigid.

Resistance to install becomes larger as the surface friction increases. The project came to a yellow sign during the last phase of installment deeper than GL-45m, as 669,300kN more was necessary to complete installment.

There were two options: increase power to install or reduce resistance. In this project, approximately 57,000m^3 of water was poured into the caisson first to make it heavier. Secondly, the ground between the caissons was drilled using a high-pressure drill, and the friction was reduced using 40MPa high-pressure water. As a result, the surface friction was reduced by 242,800kN, making the power to install larger than the resistance.

5. Final Results of Construction Accuracy

Various measurements and figures from the GPS automatic displacement measurement system showed that the final inclination was 1/2,000 (34mm). The simultaneous installment of two caissons was highly accurate.

6. Conclusion

The fifth phase of the Senjusekiya Pumping Station construction is currently ongoing. This is to connect the two caissons by drilling the 2.0m distance between them.

Japan's Largest Waterway Tunnel, which Reduces The Discharge of up to 600 m³/s

— Amagase Dam Redevelopment Project, Construction of Stilling Basin and Others —

Hironori TAKENAKA ▶ Deputy Director, Biwako Office,
Kinki Regional Development Bureau,
Ministry of Land, Infrastructure, Transport and Tourism

Introduction

The main purpose of the Amagase Dam Redevelopment Project is to strengthen the flood control function by increasing the dam discharge capacity from the current maximum of 900 m^3/sec. to 1,500 m^3/sec. Most of the tunnel discharge facilities are built underground to preserve the landscape (Fig.1). Of these, the stilling basin dissipates the discharged water from the main gate (up to 600 m^3/sec. at a water pressure of about 50 m in height difference) before it flows into Uji River. Based on the hydraulic model experiments, the stilling basin is designed to have an extremely large cross-section with the inner space of up to 500m^2, although its total length is as short as about 170 meters (Fig. 2).

Fig. 1 Layout of tunnel-type discharge facility

1. Characteristics of The Project

First of all, the stilling basin has an extremely large cross-section. Secondly, its geography and geological conditions are such that the overburden depth is about 40 meters, the overburden ratio is small (about 1.5 D) and a sharply defined F-0 fractured zone of about 10 meters in width crosses at about 80 meters from the entrance of the tunnel. Since the cross-section is extremely large, the effect of displacement and stress generated in the weak layer have strong impact on it and thus new reinforcement work is required especially for the F-0 fractured zone. As a result of the examination, the method to construct a column-shaped downward large forepiling (hereafter referred to as "RC pillar supports") by caisson type pile work on the outside of the cavity main body sidewall was newly conceived to reinforce the section with

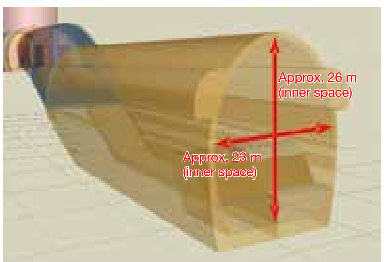


Fig. 2 Completion image of stilling basin

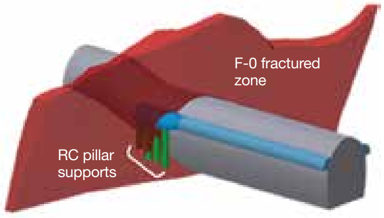


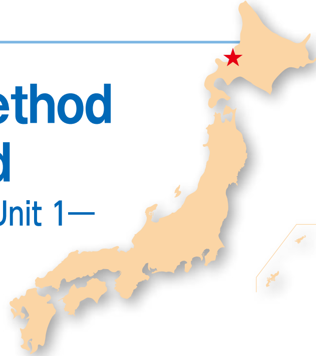
Fig. 3 Layout of RC pillar supports

fractured zone crossing (Fig. 3).
The third characteristic is the complicated construction step requiring the repetition of excavation and lining. The side drift excavation, construction of RC pillar supports and concrete lining for sidewall drift were carried out in advance, and the top heading construction is completed by the arch excavation and arch lining. After that, bench excavation (bench height 3 meters) is carried out for the lower half, and a bottom plate and a side wall are constructed to complete the waterway tunnel.

2. Computerized Construction

For an extremely large section like this, it is crucial to carry step management, such as observing the change of the geology, measuring and monitoring the ground behavior, checking the support structure, and main body structure at each construction stage against the predicted value and making adjustments. Therefore, computerized construction is carried out during the excavation, with observing the tunnel face and the wall surface and constantly measuring the ground behavior and the stress generated at the supports and lining by geology experts. In lining concrete as well as excavation, pressure gauges are installed on the travelling form to check whether the concrete pressure is appropriate for the actual lining thickness, thereby preventing the generation of void behind lining. In addition, a computerized construction method is adopted in such ways as confirming whether a form has reached the standard strength for demolding by automatically measuring the accumulated temperature.
At present, the bench excavation has been completed to the third stage, and the bench excavation and lining work for the remaining four stages (H = 11.5 m) are to be conducted. The construction will be carried out safely while feeding back various data of the construction to the next step.

Photo 1 Bench excavation, 3rd stage



World's First Use of Liquefied CO_2 Freezing Method for Protection of Shield Arrival Area in Seabed

— Construction of Discharge Channel Tunnel, Ishikari Bay Shinko Power Plant Unit 1—

Daiki HATAKEDA ▸ Hydropower Dept., Hokkaido Electric Power Co., Inc.
Akihiro MUKAI ▸ Hokkaido Branch, KAJIMA CORPORATION
Satoshi ABE ▸ Civil Engineering Design Div., KAJIMA CORPORATION
Yuta SHIOYA ▸ Engineering Development Dept., Chemical Grouting Co., Ltd.

Introduction

The discharge channel tunnel of Ishikari Bay Shinko Power Station constructed by slurry shield method is an undersea tunnel with an inner diameter of 4.7 m and a total length of 1,045 m that connects to the discharge outlet installed under the seabed. This paper reports the overview and construction results of the protective work for shield arrival area by the new freezing method using liquefied CO_2 as a secondary refrigerant.

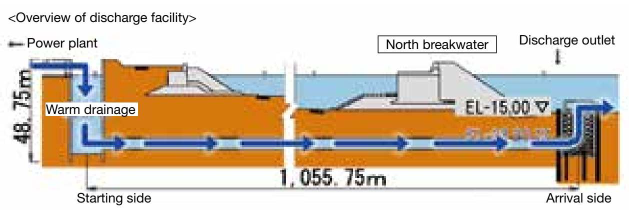


Fig. 1 Overview of discharge channel tunnel

1. Freezing Method Using Liquefied CO_2

Fig. 2 shows the comparison between the new and conventional methods. Conventionally, sensible heat generated by the thermal difference between antifreeze (brine) and ground was utilized, and CFCs, the subject of regulation, were used for primary refrigerant. In the new CO_2 freezing method, heat is taken from the ground not only by sensible heat but also latent heat due to the evaporation of the liquefied CO_2. The vaporized CO_2 is re-liquefied through heat exchange with NH3, a primary and natural refrigerant.

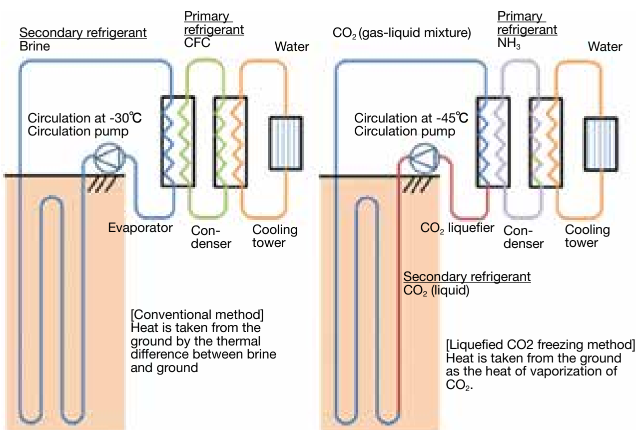


Fig. 2 Conventional (left) and new methods

Latent heat of CO_2 is larger than sensible heat of antifreeze solution, so it can form frozen soil of the same size at a flow rate of about 1/10 of the conventional. Also, the viscosity of CO_2 is about 1/90 of that of antifreeze solution, so the pipe diameter and the pump power can be reduced, and long-distance pumping is possible. Thus, CO_2 freezing method is extremely advantageous in terms of workability, work period and cost. It is a promising method with high environmental impact reduction effect.

2. Construction Results

Installation of the freezing plant was completed about a week after the shield machine arrived. Fig. 3 shows the layout of each facility. The main pipe for CO_2 was installed under the railroad sleepers to secure the flow line of the disassembled materials. The connecting work was carried out under constant monitoring of the freezing temperature. No flooding occurred at the time of connection and completion of construction.

(a) Main pipe (b) Refrigeration system

Fig. 3 Layout of each facility

3. Short Construction Period

The freezing operation was carried out smoothly without interfering with the machine dismantling operation and the process was shortened by about one month compared to that of the conventional method. Power consumption was reduced by about 40%, contributing significantly to cost reduction and environmental impact reduction.

4. Conclusion

In this construction, the big challenge was safe connection of the shield machine and the undersea water discharge outlet under high water pressure. The liquefied CO_2 freezing method was adopted for the first time in the world as a protective work for shield arrival area, and the machine dismantling work was carried out in parallel. As a result, the work period was shortened by about a month, and quick and safe connection and disassembly operations were realized. It also contributed to mitigating global warming by reducing power consumption by about 40%.

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SP-MAPS®
— Scanning and Projection Mapping System —

Yasuhisa AONO ► SHIMIZU CORPORATION

The measurement and its visualizing system that integrates the three-dimensional laser scanning and the projection mapping technology, SP-MAPS® (Scanning and projection mapping system) has been developed. Using the system, an image is projected directly on the invert excavation in a mountain tunnel, showing the difference between the designed and actual shape of the excavation surface. In the conventional method, the excavation degree of invert is controlled by using a marked rod and a string. But it is time-consuming, and it requires more manpower and entails greater risks of injuries and accidents.
The SP-MAPS® operation such as setting of the equipment, 3D scanning and the image projection can be conducted by one person without entering the excavation site. Thus, labor saving and safety improvement for confirming the excavation shape are expected. The visibility and the accuracy of projected images were examined by the field test.

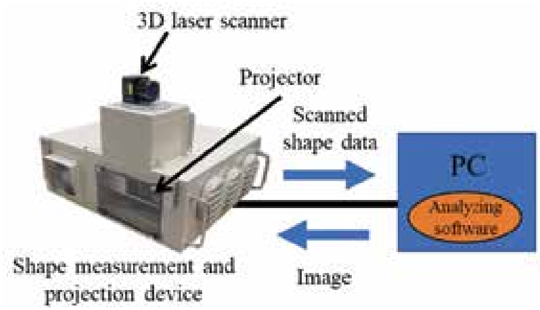

Fig. 1 Configuration of equipment for the system

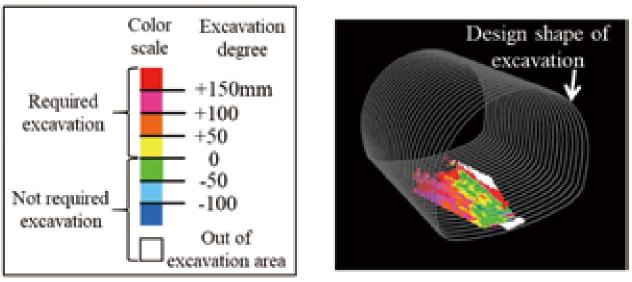

Fig. 2 Relationship between colors and positions of projected points

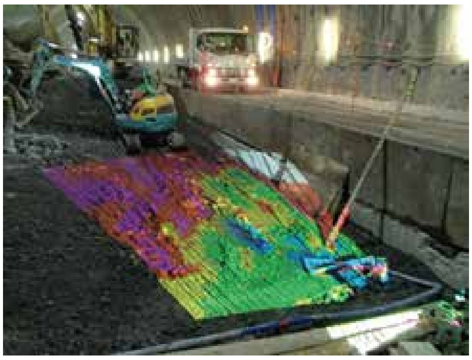

Photo 1 Projected image on the excavation area

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Cutting Face Projection Mapping System

Takuya TANI ► Senior Research Engineer, Geotechnical Research Section,Infrastructure Technology Research Department, Taisei Advanced Center of Technology

The Cutting Face Projection Mapping System projects natural ground information, at the touch of a few buttons on the projector situated on the drill jumbo, using the cutting face as a screen. Natural ground information that can by projected include: photos of the cutting face before applying face shotcrete, hardness contour diagrams that were assessed by the drill energy of drilling the shot hole or exploration drills ahead of tunnel face, cutting face observation sketches, etc.
The system projects images without contortions regardless of the shape of the cutting face by using its functionality to cooperate with surveying instruments installed inside the tunnel. Projecting images on the cutting face applied with shotcrete for safety ensures that all workers are aware and shares the condition of the tunnel face and the hardness of the natural ground, contributing to efficiency of the construction as well as safety.

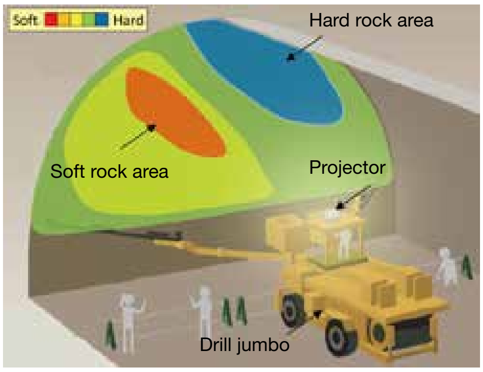

Fig. 1 Image of the Cutting Face Projection Mapping in Use

Photo 1 Projection of a Drill Hole Energy Contour Diagram

Photo 2 Projection of a photo of the Cutting Face

Geological Evaluation of Tunnel Face Using Artificial Intelligence

Koji HATA ► General Manager, Geotechnical Engineering Department, Technical Research Institute, OBAYASHI CORPORATION

In the new evaluation system, AI determines the geology of the tunnel face.
The AI incorporates knowledge and experience of experts in rock mechanics and geology.
When an image of tunnel face is uploaded to a cloud server, AI immediately determines the geological conditions such as weathering alteration and crack condition.
The field engineers use the results to select support design and auxiliary construction methods for the tunnel.

Features of this AI system

(1) Use of deep learning
- It utilizes a multi-layered neural network "AlexNet".
- Learning data based on the evaluation of 70 tunnel face is used for geological evaluation.

(2) Use of cloud computing system
- Anytime, anywhere, anyone can evaluate the bedrock appropriately in a short time. (Figure 1)

(3) Evaluation by subdividing the face
- Unlike the conventional 3 division method, the tunnel face is divided into about 70 parts for evaluation. (Photo 1)

(4) High hitting ratio
- Compared to geological experts, the system can get correct answers with hitting ratio of 70 % or more on seven items — strength of bedrock, weathering alteration, crack interval, crack condition, strike dip, amount of sump water and degree of deterioration.

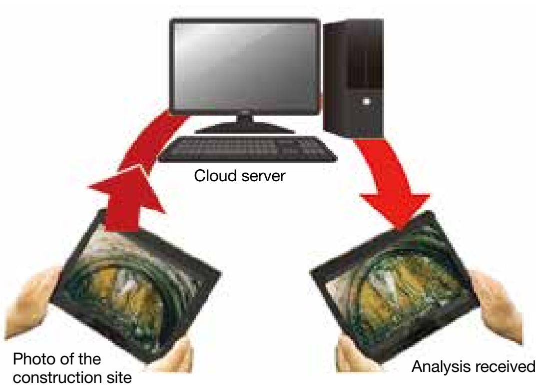

Fig.1 AI system for tunnel face evaluation

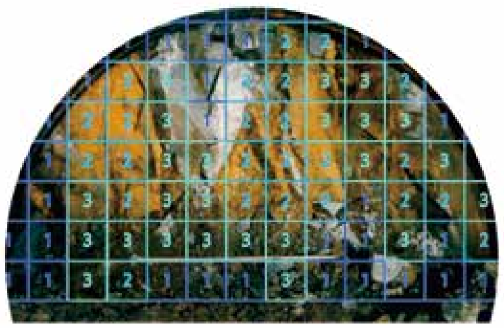

Photo 1 Evaluation of bedrock: heat map (subdivided evaluation)

Development of an “Excavation Cycle Evaluation System” using Artificial Intelligence that Automatically Recognizes Tunnel Face Works

Yoshitaka Mitsui ► Chief, The Technical Research Institute, Nishimatsu Construction Co., Ltd.

Overview

Recently, issues are increasing regarding shortage of labor and succession of skills to younger generations, due to the natural decrease in population. Many construction works in mountain tunnels are based on experience and instinct, and the impact of these issues are significant. Automation of construction work resulting in increased productivity and safety is anticipated as well. This is the background of developing the “Excavation Cycle Evaluation System” using Artificial Intelligence (AI) that automatically recognizes tunnel face works, as the basis of automation of construction.

System Features (Fig.1)

Configuration: network camera (Fig. 2), a cloud server, and a personal computer terminal.
Realtime evaluation of the tunnel face works by AI using the live footage from the network camera.
The AI can continue learning by itself using its teaching data construction function.
Data including images and AI evaluation results are stored on a cloud server, which allows headquarters and other branch offices supporting the project to view the data using a web browser.

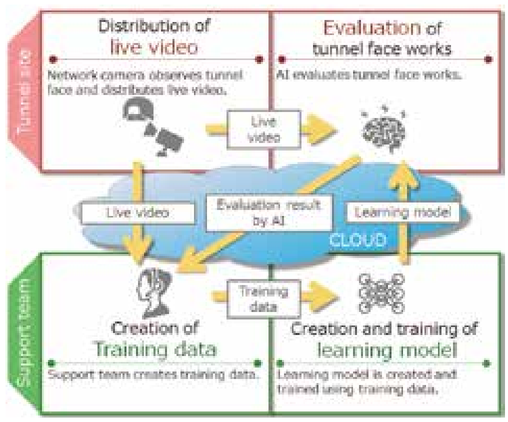

Fig. 1 "Excavation Cycle Evaluation System" diagram

Expected Results

Increased productivity by improving drill cycle through learning and analyzing tunnel face cycle time.
Promoting automation of construction works by using the evaluation data to control heavy machinery and ventilation systems.

Fig. 2 Installed network camera

Fig. 3 Example of real time evaluation display

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Automatic Tunnel Geological Condition Analysis System Using Multi-Spectral Images

Ryosuke TSURUTA ► Project Manager, Construction Division, HAZAMA ANDO CORPORATION

System Summary

This system photographs a multi-spectral image of a tunnel's face, then analyze it with AI to determine how much bedrock weathering has occurred.
A distribution map (Fig. 2) of the cutting face's degree of weathering is automatically created from the multi-spectral image only by an AI. The AI learns the relationship of "spectral reflection intensity curves obtained from each areas of the multi-spectral image (Fig. 1)" and the "area of weathering determined by the engineer's observation of the tunnel face" using both as teacher data.
"Spectral reflection intensity curves" and "weathering" relationships of around 5,000 areas in groups of granite, andesite, tuff, and other rocks were given to the AI to build the algorithm to determine the degree of weathering. As a result, the AI learned to determine the degree of the weathering of a bedrock with equal accuracy as geological engineers.

Actual Usage of the System

A measuring vehicle that has a light source and can automatically obtains multi-spectral images (Photo 1) was brought to the construction site. A program that automatically processes measurement to data output was developed. With the vehicle and the program combined, geological information of the tunnel face can be obtained automatically in a short time.
The vehicle also has systems installed to measure the intensity and conditions of cracks of the bedrock, which are both important indicators to evaluate bedrock.

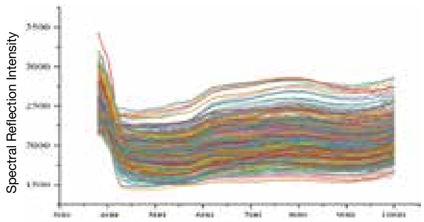

Fig. 1 Sample of a Spectral Reflection Intensity Curve

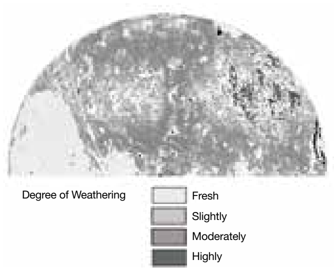

Fig. 2 Sample of an Auto-analysis Using the System

Photo 1 Measurement Vehicle

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Tunnel Face Stability Prediction System "TFS-learning"

Junichi TATSUMI ► Manager, Civil Engineering Div., Hazama Ando Corp.
Haruka GOMI ► Civil Engineering Div., Hazama Ando Corp.

In the construction of mountain tunnel, loading of explosives into blast holes and construction of steel support are fraught with hazards such as falling rocks and collapse from the working face. Therefore, it is crucial to grasp the stability of the tunnel face and take appropriate safety measures.
TFS-learning (Tunnel Face Stability calculation system by machine learning) was developed in 2016 to predict the stability of the exposed face after blasting (Fig.1).
In this system, the stability of the exposed face is predicted by using perforation data (drilling speed, attack pressure, rotational pressure and feed pressure) collected from blast holes drilled on tunnel faces by hydraulic rock drills, drilling logging etc. Face assessment scores are used as evaluation index of tunnel face stability, making the prediction quantitative and highly accurate. In addition, the predicted tunnel face stability is displayed on the screen shown in Fig. 1 in a color contour diagram with the unstable parts in warm colors and the stable parts in cold colors. This technology has been applied to many mountain-tunnel sites in our company as a technology to visually confirm the safety of tunnel face operations. In 2018, new functions were added to the system, including the one to predict the face assessment scores in front of the tunnel face and to judge the grade of bedrock by using long drilling data (Fig. 2) such as long face bolts and drilling logging. The system is expected to be useful in the future for the selection of the optimum support pattern and auxiliary method for excavation sites.

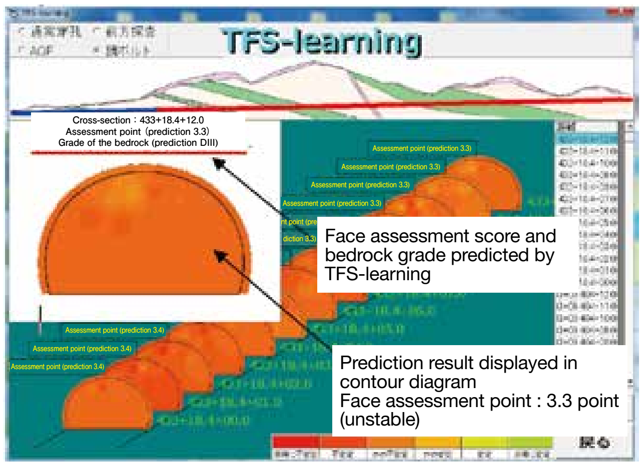

Fig. 1 The screen of TFS-learning system

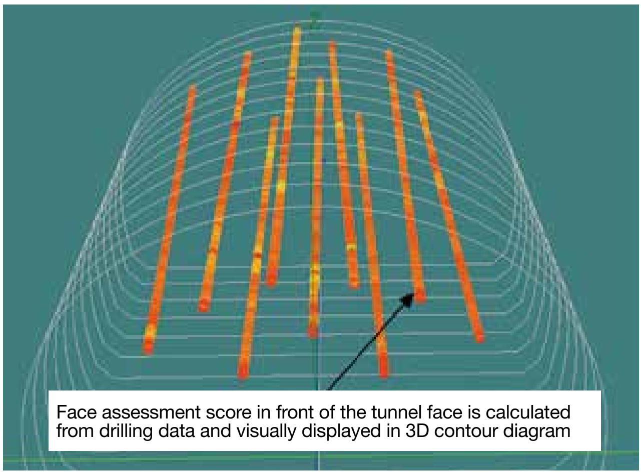

Fig. 2 An example of long face bolt drilling data

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Face Condition Viewer

Hironori SATO ► Takenaka Civil Engineering & Construction Co., Ltd.

Face Condition Viewer is an alarm system that alerts the danger of collapse of the tunnel face by utilizing ICT to predict rock falls, collapse, and cave in of a tunnel during construction. Technology used for this system obtains the real-time movement of the tunnel face pushing forward. By comparing to conventional observation of movement of the tunnel face, the system can predict rock falls, collapse, and cave in of a tunnel earlier before it happens. Alerts are projected on the cutting face, as a direct, visual alert. At the same time, Augmented Reality (AR) technology is used to superimpose the dangerousness of collapse of the tunnel face on the images of the tunnel face on wearable devices and other screens. Three-degree color schemes and circle sizes are used on the tunnel face images, where the tunnel face is split into meshed blocks. The system allows to detect tunnel face movement pushing forward and display them on wearable devices and other screens, which was difficult to recognize by manual inspection. The system is used along with workers monitoring the tunnel face manually to alert workers near the tunnel face to evacuate or carefulness, which is helpful in increasing the safety of workers in case of rock falls, collapse, and cave in of tunnels.

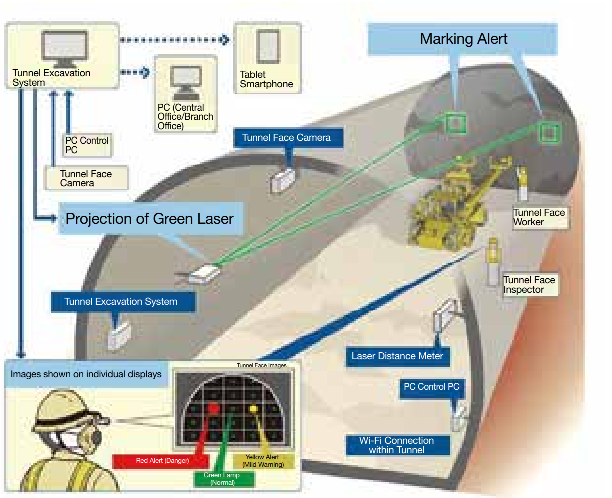

Fig. Summary of Face Condition Viewer

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Face Collapse Detection System: Rock Fall Finder

Daisuke FUJIOKA ► Geotechnical Engineering Department, Technical Research Institute, OBAYASHI CORPORATION

In the mountain tunnel construction, constant monitoring for a sign of face collapse is crucial to prevent labor accidents from rock fall. In Japan, it is mandatory to appoint a full-time face guard for the construction of tunnels with cross sections of 50 m^2 or more, but finding all signs pebble falls visually has been difficult.
Rock Fall Finder detects the pebbles falling from the tunnel face, a sign of face collapse, by image processing technology and immediately issues an evacuation alert to face worker. Monitoring the whole tunnel face with the webcam in addition to the conventional visual monitoring drastically improves the safety of the face operation and contributes to the prevention of labor accidents.

The features of Rock Fall Finder are as follows.

- A warning light, a buzzer, a webcam and a laptop computer are installed in a tunnel jumbo. Monitoring state can be checked on a tablet (Fig.1).
- Using an image processing technique called background difference method, it detects a rock fall within 0.5 seconds. At the same time, a warning light and a buzzer give an alarm (Fig.2).
- It excludes the movement of people and heavy machines from the monitoring area to monitor only the falling rocks.
- Easy to operate, it can be handled by anyone.

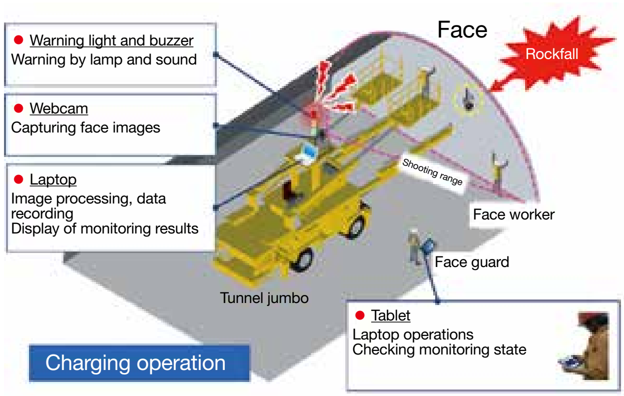

Fig.1 Detection system

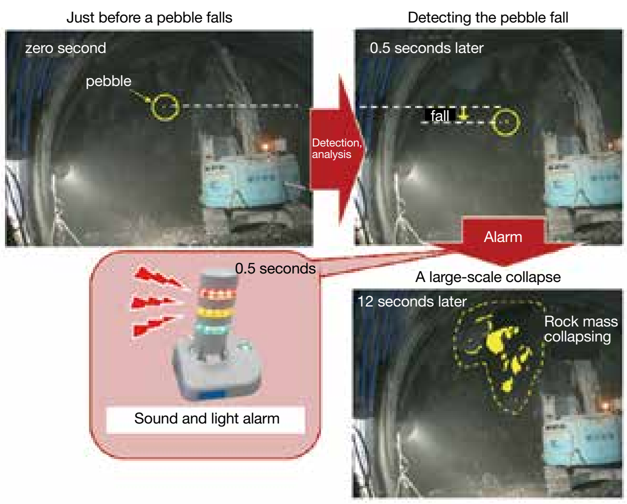

Fig.2 Rockfall detection using moving image during excavation

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Guidance System to Enhance Productivity of Scaling

Takaaki INUZUKA ► Construction Technology Department
Machinery Division,
KAJIMA CORPORATION

Background

During excavation of mountain tunnels, uneven parts remain after blasting, so each blasting needs to be followed up by inspection for scaling. Usually, the tunnel face monitoring worker (tunnel worker) visually inspects and determines any existence of scaling, which causes mistakes. When the natural ground is chiseled more than necessary, it cause loss of cycle time and shotcrete. Also, as the manual inspection by tunnel worker would be done near the tunnel face, where the ground is loose after the blasting. This could cause dangers such as rocks falling.

Summary of the System

The system measures the shape of natural ground after blasting using a high-speed 3D scanner. Required time for measurement is 1 minute. The data is superimposed on the cross-section design of the tunnel. The scaling parts are shown in color, to make it visually understandable. As rock bolts from the design would be drawn into the analysis, it is easy to find the actual scaling. Results are shown 30 seconds after scanning, and as the whole tunnel face would be analyzed in one measurement, the time to find scaling is reduced dramatically.

Actual Usage

By using this system at actual tunnel construction sites, workers were able to locate the scaling accurately, and were able to chisel out scaling in a short time. Time necessary to remove scaling was reduced to 2/3 compared to manual inspection, and amount of shotcrete used was reduced around 15%. Safety conditions were improved as well, since workers did not have to go near the tunnel face.

Fig. 1 Scaling Detection System

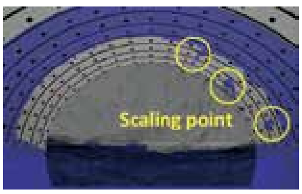

Fig. 2 Showing Scaling Points in Color

Fig. 3 Using the System at Construction Site

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Starlight Sensor System to Detect and Control the Height of Placed Lining by Light

Koki KUMAGAI ► TOBISHIMA CORPORATION
Masumi TAKINAMI ► TOBISHIMA CORPORATION

Summary

The Starlight Sensor System visualizes the height of the lining real-time as it is placed, while pouring the concrete into the tunnel lining form. The system uses innumerous illuminance sensors and LED installed on the surface of the centering to detect the height of lining as it is being placed.

Specifications

Fig. 1 shows the positions of the illuminance sensors and LED. The light coming from the LED on the surface of the centering brightens the construction space and reflects on the waterproof sheet to be irradiated on the illuminance sensors. When the concrete gets poured into the tunnel lining form, the light is obstructed and does not reach the sensors. As the electric resistance values change according to the intensity of the light, user can determine that the change of the value of an illuminance sensor on the control PC means that the pouring of concrete was completed to that position. Setting a timer on the form vibrator to activate at the positions where the pouring was finished would allow automation of compaction.

System in Use

Fig. 2 is the UI of the system. The parts colored blue are the places where the concrete was poured. The actual construction space would be illuminated by the many LED installed, and this also contributed in increasing work efficiency and safety.

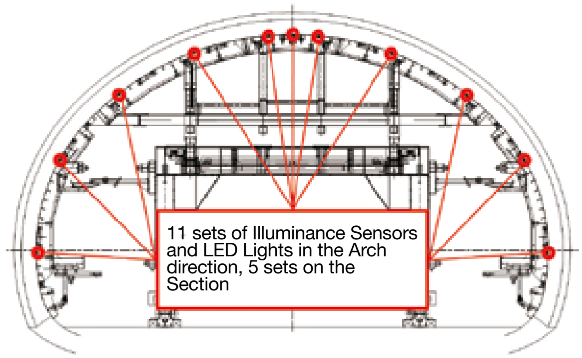

Fig. 1 Positions of the Illuminance Sensors and LED Lights at the Centering

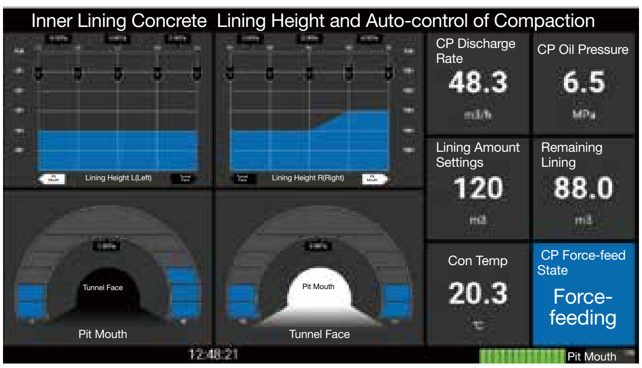

Fig. 2 Sample Image of the System UI

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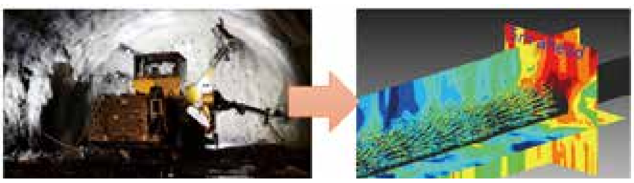
Geological Evaluation Technology for Rock Tunnelling Using ICT
— Smart Face Watcher —

Yasuyuki MIYAJIMA ► Chief Research Engineer, Kajima Technical Research Institute
Suguru SHIRASAGI ► Chief Research Engineer, Kajima Technical Research Institute
Hayato TOBE ► Senior Research Engineer, Kajima Technical Research Institute
Takuji YAMAMOTO ► Executive Research Engineer, Kajima Technical Research Institute

Overview
In tunnel construction, it is very important to choose appropriate support systems according to geological conditions to ensure quality and safety. However, in the daily excavation cycle, it is difficult to predict the geological conditions and to fully grasp conditions of the tunnel face without overlooking any problems. To prevent any geological troubles, we developed the system "Smart Face Watcher". It consists of two analysis methods: "3D real-time geology forecasting system" and "rock fall risk assessment system".

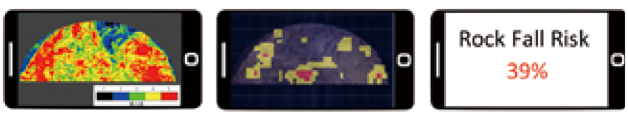
3D Real-Time Geology Forecasting System
Figure 1 shows the procedure of the forecasting system. All drilling data acquired by the auto-controlled face drilling rig is automatically transmitted to a computer located in a field station. Then, the function to predict the geological conditions ahead of tunnel face is activated automatically. It estimates the distribution of drilling energy in the analysis area by geostatistics within ten minutes and the prediction results can be confirmed in the field. The results can be used to decide on the next cycle including auxiliary methods.

Rock Fall Risk Assessment System
We focused on the weathering and crack situations of the rock mass which seemed to be highly related to the occurrence of rock fall from the face. This system quantitatively evaluates the degree of weathering of the rock mass and the density of crack crosses by image analysis. The system is installed on the smartphone. After the face is photographed with a smartphone, analysis automatically gets started, and after 10 seconds, the results are confirmed as shown in Fig.2. The results can be used to determine the appropriate thickness of the face shotcrete to prevent rocks from falling.



Drilling by auto-controlled face drilling rig — Prediction by ordinary kriging

Fig.1 3D real-time geology forecasting system



Weathering levels — Density of crack crosses — Rock fall risk

Fig.2 Rock fall risk assessment system

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Steel Arched Support Erection Robot

Kazuhiko MIZUTANI ► MAEDA CORPORATION

Fall of loosened rock at the tunnel face is an industrial incident specific to mountain tunnels, and cases of such disaster are most heard of when erecting steel arched supports. To prevent such incidents, there is a need to combine and conduct measures such as suppressing the loosening of ground, predicting rock fall, and safety measures to protect workers. These measures are taken to reduce disaster rates, but they are not fundamental resolutions. If workers did not have to work at the tunnel face, such incidents would not happen in the first place.

With such understanding, we developed the "steel arched support erection robot", which allows workers to install steel arched supports in mountain tunnels without stepping into the tunnel face area.

The robot consists of the "support location navigation system" including an automatic tracking total station, a "high-grade erector" that can make fine adjustments to the support position, and "steel arched supports for automatic erection" that does not need bolt and nut fastening. This system allows machines to do the work humans were doing at the tunnel face, namely measurement and adjusting support positions. As machines grip onto the steel supports while applying shotcrete, the worker can stay in the operator's seat to conduct highly accurate support erection. This system requires only one operator to erect supports, and with no humans working right beneath the tunnel face, safety and productivity is boosted greatly.

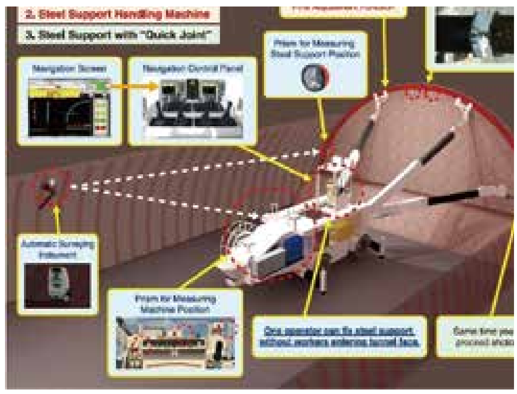

Fig. 1 Summary of Technology

Fig. 2 Photo from the Front of a Support Erecting Robot

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Fore-Plate Method

Masashi NAITOU ► Deputy General Manager,
Civil Engineering Dept.,
TODA CORPORATION

Fore-poling with three-meter-long bolts to stabilize the crown is the usual option when drilling poor natural ground using NATM. The fore-plate, on the other hand, is a method that represses the looseness of natural ground by placing steel sheet-piles using no drilling fluid.

Fore-poling is implemented using a drill jumbo, by drilling a hole using drilling fluids, applying mortar to the hole, and placing bolts. This method, though, may promote further loosening of natural ground, especially with poor natural ground, especially with sandy soil. So, our team focused on the idea of using steel sheet-piles, which require no pre-drilling, instead of bolts. We also made improvements on general purpose drill jumbos, so the piles can be implemented by machine and not by hand, as they were conventionally.

This improved machine can be used by attaching special rods and centralizers, which were newly developed for this process, on the guide cell of the drill jumbo. Attachments can be changed, so one can use the same drill jumbo for rock-bolt drilling, for example.

Compared to rock-bolts, steel sheet-piles can support the natural ground better, and less dirt fall through any cracks, as the size and bending rigidity are larger. Construction time can be shortened to half of the conventional method as the required time for installing sheet-piles as the same as drilling rock-bolts, and the process of applying mortar and inserting bolts are unnecessary.

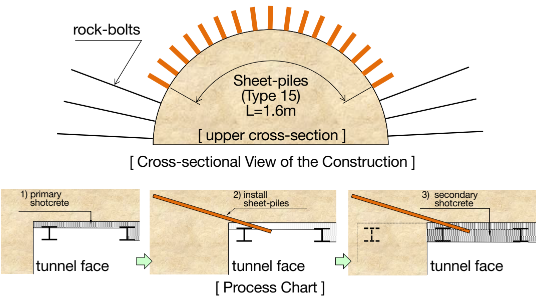

Fig. 1 Outline of the Fore-plate Method

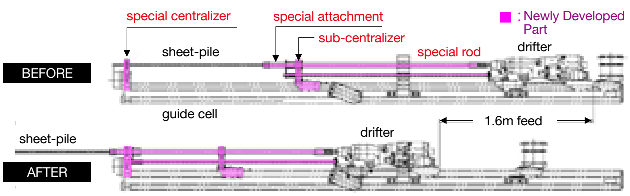

Fig. 2 Sheet-pile Installation Device

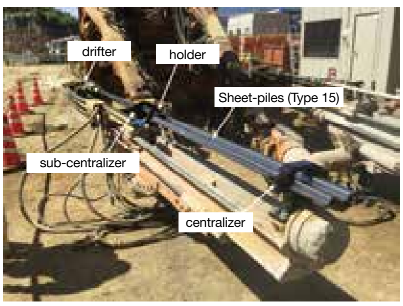

Fig. 3 Sheet-pile Installation Device Loaded on a Guide Cell

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Automatic Calculation of Appropriate Amount of Explosive for Tunnel Blasting Based on Drilling Data in Excavation

— SMC Tunneling Series "Automatic Smooth Blasting" —

Takaaki KOIDE ► Manager, Tunnel Technology Group, Civil
Engineering Technical Consulting Dept.,
SUMITOMO MITSUI CONSTRUCTION CO., LTD.

This system is used for drilling and explosive charge in blasting excavation of mountain tunnels. Based on drill logging data such as drilling velocity and pressure of rod turning obtained when drilling charge holes with drill jumbos, the bedrock conditions ahead of the excavation face is grasped and assumed, and the appropriate amount of explosive is automatically calculated and displayed on the monitor. After blasting, the excavation face is measured in three dimensions, and the relationship between the amounts of explosives and overbreak is analyzed and fed back to the automatic calculation of the amounts of explosives to improve its accuracy. This reduces overbreak and shortens the construction cycle, and makes drilling and explosive charge more efficient.

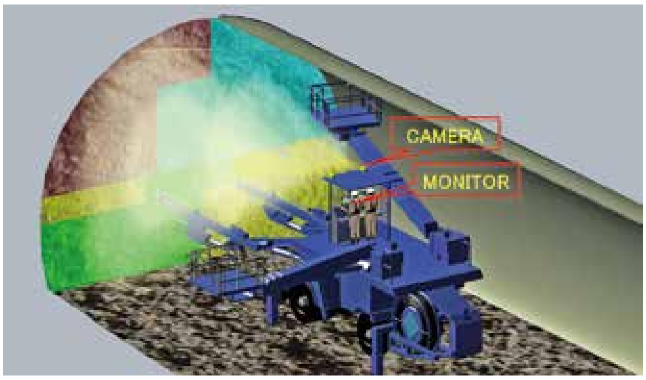

Fig. 1 Image of system

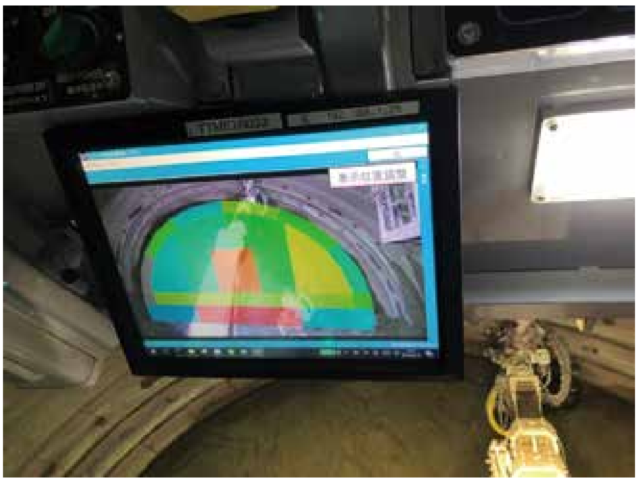

Fig. 2 Mapping on monitor

Full Precasting of Large Underground Structures Using Circular Segments

— Development of Super Ring Method —

Masahiro MASUDA ▶ KAJIMA CORPORATION

Super Ring Method is a precast method in which segments set above ground are assembled in a circle, firmly integrated into a ring form by prestressing, hung down into an open underground space and connected underground to form a structure. This is an epoch-making precast method that addressed the challenges posed by conventional methods (cast-in-place concrete method, precast method) such as process shortening, labor reduction, improvement of cut-off performance and cost reduction through a change in the body shape from rectangular to round. Figure 1 shows the construction procedure.

Full-scale construction experiment (See photos 1 to 3)

A full-scale experiment was carried out to confirm the quality and workability of the Super Ring Method. A segment with outside diameter of 12 meters (equally divided in eight parts) was assembled and a total of four rings were made above ground, lifted, set underground, slid and integrated.
As a result, 1) segments were assembled into almost perfect circles without joint offset, 2) the stress, deformation and opening of joint were within the predicted range, 3) high cut-off performance was confirmed in cut-off experiment and 4) construction was smoothly carried out witha small number of people (7 workers).
Thus, it was confirmed that the method had no problems in quality and workability.

Photo 1 Assembly of segments above ground

Photo 2 Liftup

Photo 3 Assembly of 4 rings completed

Features of the construction method

1) The assembly of segments above ground and integration of the rings underground can be separately and simultaneously conducted. This can drastically shorten the process (to 1/2 of cast-in-place method) and reduce the number of workers.
2) Segments manufactured in factories are assembled in almost perfect circles above ground, so the body is excellent in cut-off performance with little opening and misalignment.
3) The circular structure, which is dynamically advantageous, allows for the reduction of the weight of the components to about 1/4 of that of the cast-in-place construction as well as the reduction of the amount of concrete and cost.
4) This method is suitable for urban areas with limited working space because the construction yard is fixed in one place, where rings are lifted, set underground and slid, the jack equipment is simple and no reaction walls are necessary.

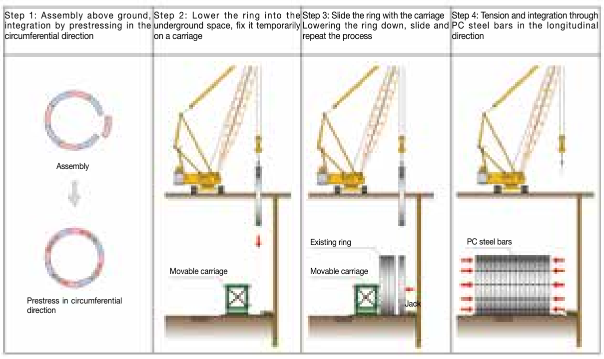

Fig.1 Construction process

Development of The Next Generation TBM Equipped with Conventional Tunneling Mode

Yoshinori KITAMURA ▶ KAJIMA CORPORATION

KAJIMA and Komatsu co-developed the world's first hybrid excavator which can convert TBM mode into conventional tunneling mode according to the geological change. This excavator performs high-speed drilling in TBM mode for hard rock excavation and this can convert to conventional tunneling mode for weak ground excavation. Weak ground can be excavated by the operation of the bucket equipped inside the machine and tunnel supports can be installed immediately afterwards.

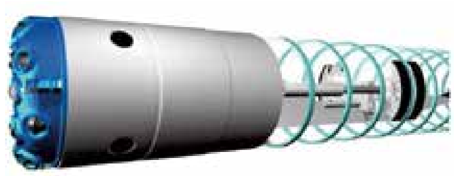

Fig.1 TBM mode for hard rock excavation

Fig.2 Conventional tunneling mode for soft ground excavation

Rapid drilling manipulating TBM mode is for hard rocks.
Like the conventional TBM, tunnel supports can be installed behind the excavator.
Appearance of weak layer can be detected by forward geological exploration.

After reaching the defective ground grasped by forward geological exploration.
The machine is retracted up to 3.0 m and secure the drilling space forward.
Then the cutter head is opend and switched to conventional tunnelling mode.

The bucket inside the machine excavates the ground.
Debris are carried out to the rear by a belt conveyor.

Steel support, shotcrete and rock bolts are installed after excavation.
Auxiliary method for a mountain tunnelling can be installed in accordance with geology.

Exclusive Rock Bolt Placement Machine that Realized Full Mechanization of Drilling, Mortar Injection, and Rock Bolt Insertion

Takahiro AOYAGI ► Civil Engineering Management Division, KAJIMA CORPORATION

Summary

KAJIMA CORPORATION developed an Exclusive Rock Bolt Placement Machine that conducts drilling, mortar injection, and rock bolt insertion continuously by one boom. This machine was built on a generic wheel loader with one boom for rock bolt placement only, two booms with baskets, and a guidance system that shows the drill position and placement angle. This machine reduces the task of rock bolt loading at high places, which is laborious work, as well as reducing the dangerous work at the tunnel face.

Structure of the Rock Bolt Placement Boom

The boom for rock bolt placement has a guide cell for drilling, a guide cell for mortar injection, and a guide cell for rock bolt insertion. The three guide cells move concentrically.
Once the machine is set, the process from drilling to rock bolt insertion can be done without moving the boom. A maximum of nine rock bolts can be loaded on the rock bolt holder in one supply.

Guidance System using Relative Coordinates

By allowing the guide cell for drilling to conduct a three-point pickup of the position of the already placed rock bolt, the guide cell can lead the operator to the drilling position and placement angle of the next rock bolt. With this system, the operator does not have to measure the absolute coordinate of the machine. As only relative coordinates necessary for determining the drill position and placement angle, time to finish the process became shorter with only the cabin operator necessary for the work.

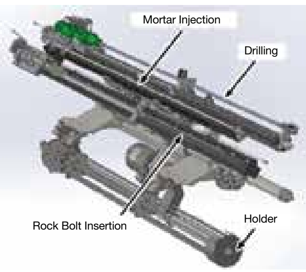

Fig.1 Composition of the Rock Bolt Placement Boom

Fig.2 Rock Bolt Placement Machine

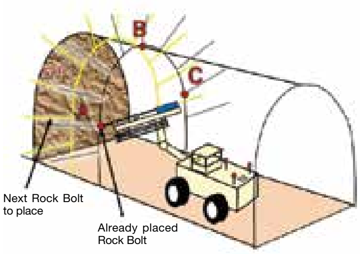

Fig.3 Structure of Guidance System

Fig.4 Guidance Screen inside Cabin

High-Fluidity Concrete with Low Cement Content "Neuro-Crete Neo®"

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Japan is facing a serious shortage of construction workers. In order to improve the productivity of tunnel lining, the use of high-fluidity concrete which requires no compaction is effective.
However, in conventional high-fluidity concrete, separation of materials needs to be prevented by drastic increase in the unit cement quantity which induces increased material cost and risk of thermal crack.
Therefore, we developed Neuro-Crete Neo®, the high-fluidity concrete with low cement content. Using a newly developed special thickening agent, it keeps high fluidity and self-compacting property while the cement quantity is equivalent to the concrete used for general tunnel lining. The features of Neuro-Crete Neo® are as follows;

(1) The high-fluidity and self-compacting property are ensured, while the cement quantity remains equivalent to the conventional lining concrete.
(2) The amount of the special thickening agent used is as small as about 60 g/m³, and it can be put into the mixer simultaneously with other materials during the concrete manufacturing with no special equipment or facility needed.
(3) The quality after curing is equivalent to the conventional lining concrete of equal water-cement ratio.
(4) High-quality tunnel lining is possible without compaction.

Photo 1 Special thickening agent (left) and Neuro-Crete Neo®

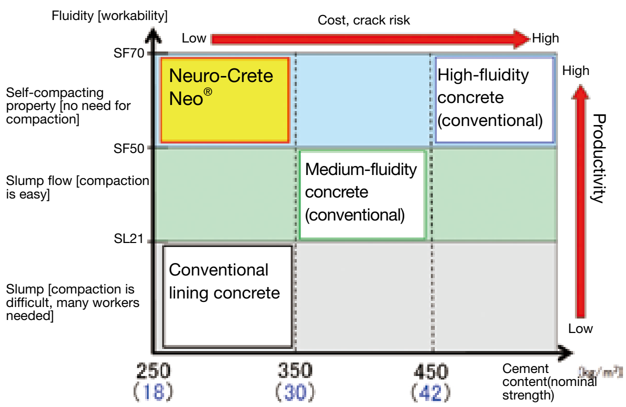

Fig.1 Position of Neuro-Crete Neo®

Should you require further details on these articles or other information on tunnelling activities in Japan, please contact:

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