

Challenges & Changes

# TUNNELLING ACTIVITIES IN JAPAN 2012

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 2012 edition of Tunnelling Activities in Japan, biennial publication of Japan Tunnelling Association. Despite the fact that in recent years tunnel construction projects in Japan are on the downturn, our country remains one of the outstanding global leaders in terms of tunnel construction volume.

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

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

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

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President  
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# Multiple Bench Cut for Excavating a Large-section Station Cavern

– The Tozai Line of the Sendai-City Rapid Railway –

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The Tozai Line of the Sendai-City Rapid Railway is a subway line 13.9 km long, planned to alleviate traffic congestion and improve accessibility to the urban center (Fig. 1).

The Aobayama station, the second station from the starting point, is located 33 m from the surface. For reducing construction cost, a part of the open-cut zone (96 m long) was changed to non-open cut tunneling of large section (164 m<sup>2</sup>) housing platforms.

The overburden of the large section cavern is 20 to 24 m. The geology of the ground to be excavated is soft rock whose N value is 50 or more.



Fig.1 Overview of the railway line

## 1 Construction of the large-section station cavern

When selecting a tunneling method for the cavern, two methods were compared, center diaphragm method and multiple bench cut method, referring to the construction results of the preceding tunneling zone (with similar geology) of the Aobayama tunnel. As a result of the comparative study, ground properties were evaluated again from the measurement data of the preceding zone to validate safety against deformation. Consequently, the multiple bench cut was selected, which was rated superior in terms of ease of work and cost efficiency.

The excavation sequence is as shown in Fig. 2: the upper half ((1) upper stage and (2) lower stage) is excavated with mini-bench (4 to 5 m long) up to the arriving position of the open cut zone, next the lower half (3) is cut to the arriving position, then the invert (4) is excavated. The excavation interval is 1.0 m, with the support pattern shown in Fig. 2.

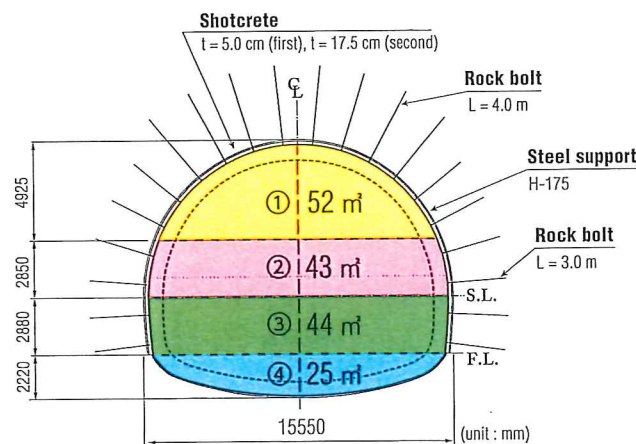


Fig. 2 Excavation sequence and support pattern

## 2 Construction results of the large-section station cavern

The excavation of the cavern started in the beginning of February 2011. The crown settlement and convergence in the top heading phase was 8 mm and 5 mm respectively, which were smaller than predicted. The earthquake off the Pacific coast of Tohoku on March 11, 2011 forced suspension of work for about six months. However, the earthquake caused almost no impact on the main structure of the tunnel. In the end of August, work was resumed, and tunneling was advanced safely and the breakthrough ceremony was held in the beginning of September. The railway tracks and equipment will be installed and service is planned to open in 2015.



Photo 1 Top heading

# Development of the SENS and Application to Tunneling in Unconsolidated Ground

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The SENS (acronym of Shield tunneling method, Extruded concrete lining, NATM, System) has been developed to create a new reasonable method for projects classified in the boundary range between the mountain tunneling (NATM) and shield tunneling. This method was first applied to the project of the Sambongihara Tunnel (3 km long) on the Tohoku Shinkansen line. The SENS was successful in view of work efficiency, safety and cost, in tunneling in unconsolidated ground where it is difficult to use the NATM effectively. The Tsugaru-Yomogita Tunnel (6 km long) on the Hokkaido Shinkansen line is being constructed by the SENS, enabling rapid advance in unconsolidated ground.

## 1 Features of the SENS

The SENS uses a closed-face type shield for excavation and constructs the primary lining with cast-in-place concrete (Photo 1). The specific components of this shield are the end form provided with concrete injection holes and pressurizing function, and the segmented tubular inner form to shape the lining.

The essential concepts of the SENS are as follows:

- Simultaneously with shield advance, concrete is placed under pressure at the shield tail, thereby maintaining the ground and constructing the primary lining (Photo 2).

- The cast-in-place lining is considered to be similar to the primary support in the NATM, and structural soundness is verified by observation and measurement. Finally, the secondary lining is built to complete the tunnel.

## 2 Results achieved by the SENS

To date the SENS has achieved an advance rate double to triple that of the NATM in excavation of the Shinkansen double-track tunnels in unconsolidated ground. This rate is comparable to the ordinary shield tunneling using lining segments. In addition, the SENS causes less impact on the surrounding ground, significantly reducing ground deformation compared with the NATM (Fig. 1).

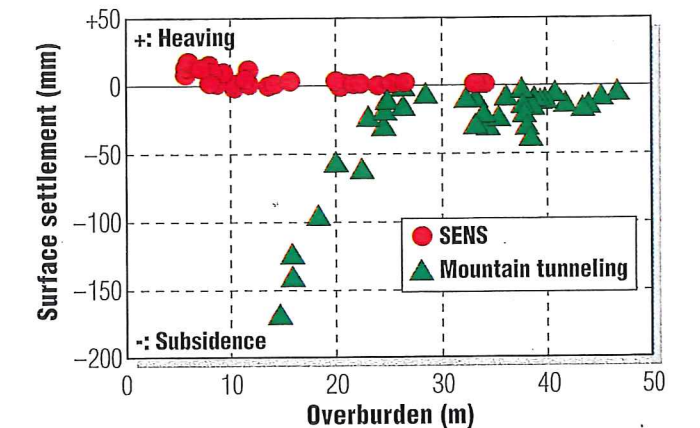


Fig. 1 Comparison of surface settlement between SENS and NATM

## 3 Potential for SENS

The SENS is applicable to a wide range of ground conditions in the boundary range between the NATM and shield tunneling. The SENS is planned to be used in urban subway construction projects instead of the other two methods, for cost reduction and safety. Its applicable range is expected to expand further.

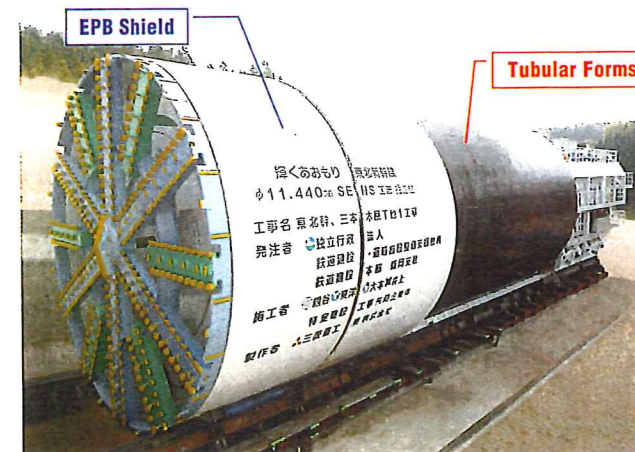


Photo 1 SENS shield



Photo 2 Completed primary lining

# Excavation in the West Zone of the Tawarazaka Tunnel on the West Kyushu Route of the Kyushu Shinkansen Line



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The west zone of the Tawarazaka Tunnel is a 5.5km-long double-track tunnel, 60 m<sup>2</sup> in cavity sectional area. The length of 3,030 m on the arriving side is the west zone. The geology of the tunneling site is largely classified into mudstone and tuff breccia. In Section I as shown in Fig. 1, squeezing pressures occurred. The geology of this Section is mudstone and the overburden is 85 m to 190 m. In Section II to be excavated, the geology is also mudstone and the maximum overburden is 260 m, where occurrence of squeezing pressures are anticipated as in Section I.

## 1 Excavation method of Section I

To evaluate the squeezing property of the mudstone, muck sampled in Section I was tested petrologically. The test results showed that although smectite content is small, with low squeezing tendency, the unconfined compressive strength and competence factor were small, 2.0 MPa and 0.75 respectively (Fig. 2). Next, a slaking test was performed, and the result was D, the worst class. These results showed that squeezing pressures were induced by expansion of the plastic zone due to stress release associated with excavation.

Measures planned to counter squeezing pressures were early section closure and use of the mini-bench cut instead of short-bench. The section was planned to be closed early with an invert strut at 10 m behind the face. The support pattern was determined, referring to examples of excavation in mudstone on the Hokuriku Shinkansen Line, and H-200 was selected for the top heading strut and invert strut (Fig. 3). The control reference value for deformation was set at around 1.5 % of the tunnel cavity.

In the area where these measures were taken, compared with the area without such measures, the displacement rate in the top heading was not significantly different, but a remarkable converging tendency appeared after installation of the invert strut, and consequently, the convergence was about 60 mm.

## 2 Excavation method of Section II

The overburden is higher in Section II than in Section I. Therefore, with the same geology, the competence factor is smaller, and greater squeezing pressures may occur. Succeeding excavation will be performed with various measures including exploration ahead of the face for grasping of the geological conditions beforehand, response in the early phase by observation of the face and control by measurement, and selecting a reasonable excavation pattern most suited to the geology by means of data collection and arrangement, and feedback.

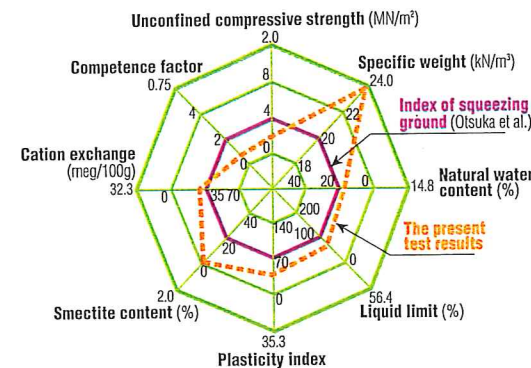


Fig. 2 Petrological test results (at 14,600 km from Takeo Onsen)

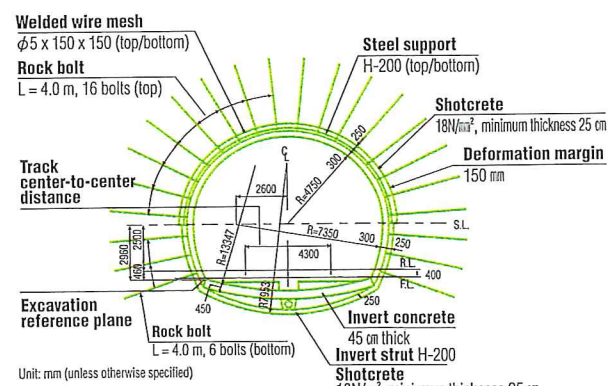


Fig. 3 Support pattern

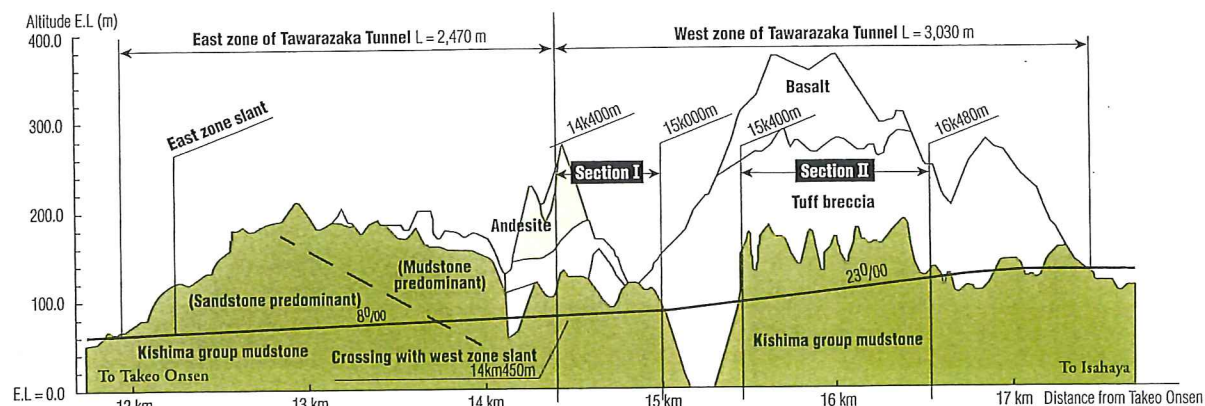


Fig. 1 Geological longitudinal section

# Tunneling with Preliminary Ground Improvement

– Kamikita and Akahira Tunnels on the Tohoku Shinkansen Line –



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The Kamikita and Akahira tunnels on the Tohoku Shinkansen line are double-track tunnels 625 m and 220 m long respectively. The geology is alternating strata of unconsolidated sand and soft clay. The overburden of the Kamikita Tunnel is less than 6 m and that of the Akahira tunnel less than 2 m (Fig. 1).

To reduce cost and increase work efficiency, the ground was improved before NATM tunneling. The ground from the surface to near the tunnel crown was excavated by open-cut, and the zone around the tunnel was improved by shallow mixing and preliminary mixing embankment. Immediately after improvement, the open cut section was backfilled and NATM tunneling started.

## 1 Design of ground improvement

The ground was improved by shallow mixing to form a portal with improved soil mass of the specified strength, to the depth near the formation level layer supporting the improved soil mass (Fig. 2).

A comparative study by two dimensional linear elastic FEM analysis demonstrated that the ground improvement down to the formation level will restrain transition into plastic state and destabilization.

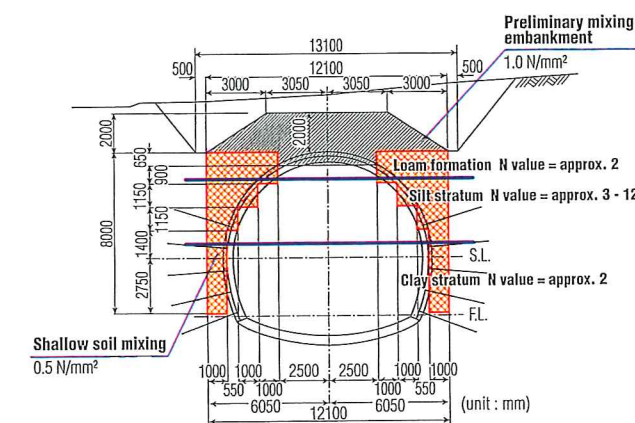


Fig. 2 Range of ground improvement and design strength

## 2 Construction results

Prior work records show that for tunnels with soil improvement to the upper side of the top excavation, the top heading displacement ratio (settlement on completion of the top heading/final settlement) is about 60%. It means that greater part of settlement occurred during top excavation. In contrast, in the present project with soil improvement that reaches the formation level, the top heading displacement ratio was relatively small, 10% to 40%, and large portion of settlement took place during bottom excavation. From the subsidence distribution measured with extensometers we learned that compressive strains were induced only at the foot of the improved soil mass (at the tunnel invert level) in this project (Fig. 3).

The measurement results were similar to the ground behavior predicted by the FEM analysis, verifying that the soil improvement increased the ground stability from the tunnel side wall to the invert.

The method selected for this project is reasonable, which needs no auxiliary stabilizing methods other than ground improvement. It may be a new option in addition to other conventional tunneling techniques such as NATM with extensive auxiliary methods and open-cut. We expect therefore it will see wider use in ground conditions similar to this project.

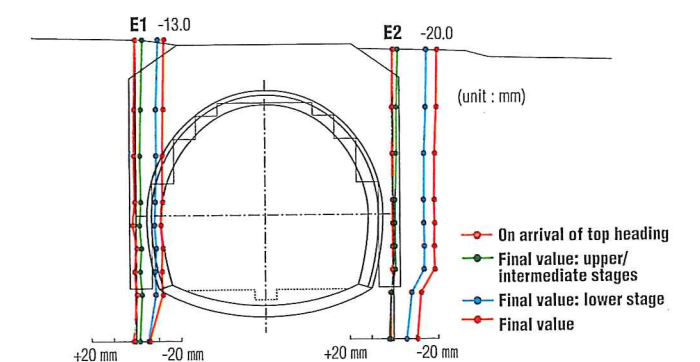


Fig. 3 Ground settlement measurements

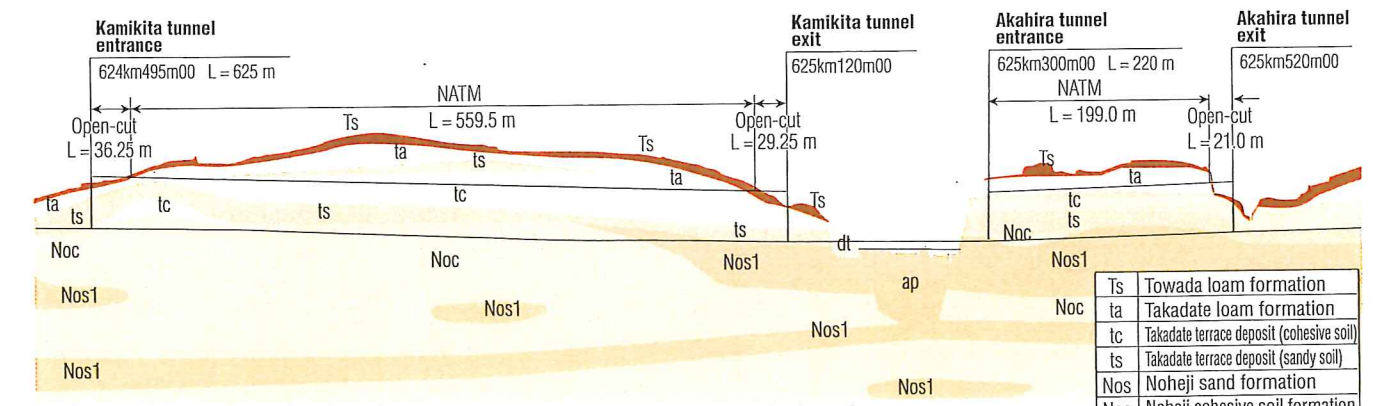


Fig. 1 Longitudinal geological section

# A Shinkansen Tunnel in an Abandoned Quarry

– Shin-Moheji Tunnel on the Hokkaido Shinkansen Line –

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The Hokkaido Shinkansen is a railway line about 360 km long between Shin-Aomori and Sapporo. The section of this line between Shin-Aomori and Shin-Hakodate (tentative name) approximately 149 km long is under construction, planned to be completed in 2015. In 82 km of this section including the Seikan tunnel (53,850 m), the longest undersea tunnel in the world, structures conforming to the Shinkansen specifications have already been completed. The new construction portion is about 67 km long (29 km on the Honshu side, 38 km on the Hokkaido side). The Shin-Moheji tunnel, located at almost the center of the route on the Hokkaido side, is 3,345 m (Fig. 1).



Photo 1. Protection embankment

material. In the slope, there are extensive traces of a collapse landslide along an old stratification. Since the landslide plane presents a dip slope of about 30 degrees toward the east side of the tunnel portal, a landslide is anticipated to occur again. To cope with this problem, a massive embankment above the tunnel route was constructed to protect the Shinkansen, and counterweight filling was provided to prevent landslides. The counterweight filling is advantageous, because it is maintenance free and excavation muck can be effectively used. The embankment geometry was determined, assuming cases where the landslide line passes below the counterweight filling and it passes in the counterweight filling (Fig. 2). The embankment is large, about 20 m high, 100 m wide and 205 m long. The tunnel was excavated after embankment by the counterweight fill method (Photo 1). The tunnel was constructed by the NATM with short-bench top heading. Excavation used a hydraulic tunnel cutter (twin header) and a large breaker.

**2 Conclusion**  
Excavation of the Shin-Moheji tunnel started in November 2007 and broke through in February 2012.

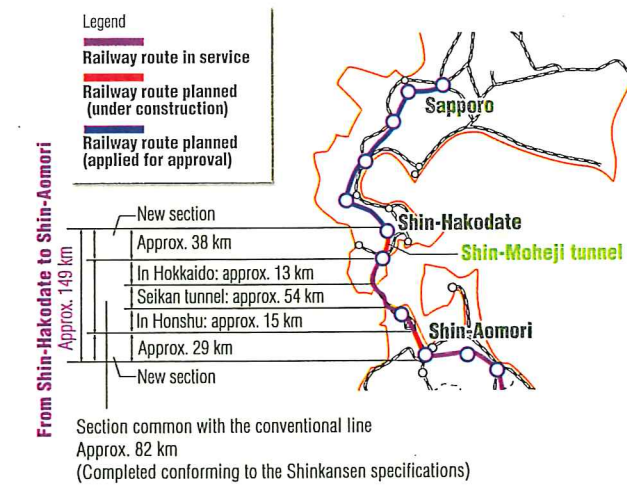


Fig. 1 Overview of the Hokkaido Shinkansen

## 1 Construction of the Shin-Moheji tunnel

The outstanding feature of this tunnel is that, in the 205 m-section from the east tunnel portal, it passes just below a large slope about 100 m high of an abandoned mine of cement raw

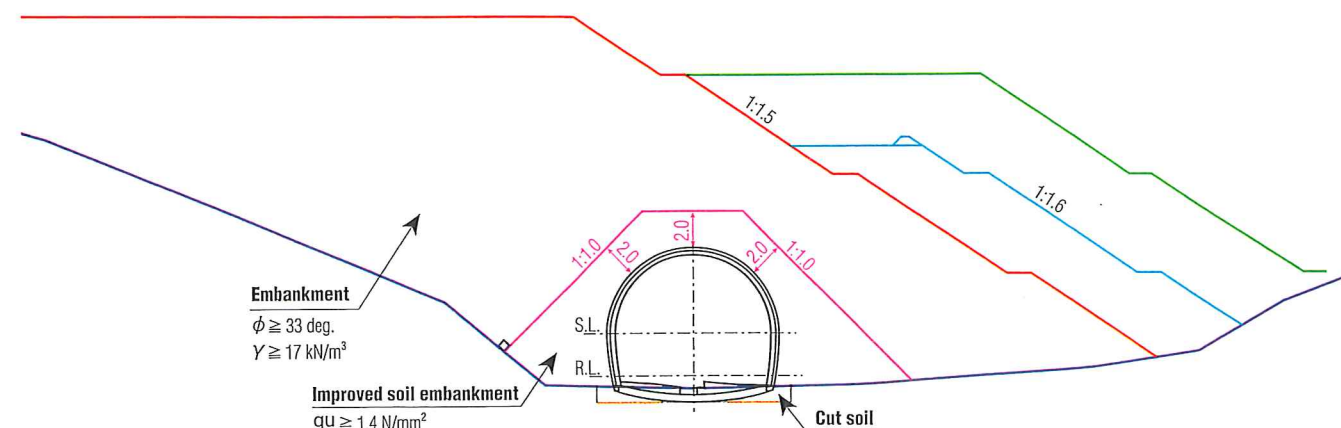


Fig. 2 Section of the protection embankment

# Chuo Shinkansen

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## 1 Overview

Tokyo, Nagoya and Kansai are the top three urban areas in Japan which are among the most densely populated places in the world.

The current Tokaido Shinkansen, linking these three areas, is serving as the main artery to support the Japanese people's life and economy.

It is now 47 years since the Tokaido Shinkansen commenced operations. It is expected that it will soon be faced with risks due to aging, and in need of preparing for coming disasters resulting from earthquakes in the Tokai area. With the view of solving these problems, the Central Japan Railway Company has set a goal of doubling the current line, in other words, construction of another bullet train line, Chuo Shinkansen, running at 500 kilometers per hour on superconducting magnetic levitation to maintain and enhance the function of the artery.

The magnetic levitation train, when put in service between Tokyo and Osaka, may offer transportation speeds which are rated as equivalent to the speed of airlines, while its CO2 emission is about one-third of that by aircraft for this distance. From this viewpoint, it can be said that the magnetic levitation train will grow as transportation means truly worthy of the 21st century in which more importance will be put on environmental preservation.

In May 2011, the Minister of Land, Infrastructure, Transport and Tourism, based on the Nationwide Shinkansen Railway Development Act, decided on the construction plan of the Chuo Shinkansen with magnetic levitation trains, between Tokyo and Osaka, and gave Central Japan Rail Company (CJRC) orders to construct the trunk line.

CJRC, on receiving said orders, is now proceeding with the procedure of environmental impact assessment for the first construction phase between Tokyo and Nagoya.

The route of the Chuo Shinkansen made public by CJRC selects a course more linear than the route of the current Tokaido Shinkansen (Fig. 1).

In the middle section of the route, it will run through a very long mountain tunnel which is planned to penetrate into the Akaiishi mountain ranges of 3,000 meters in elevation. The depth of the earth covering will be greater than any previously in Japan.

To eliminate the risks involved in the construction of such an extremely long tunnel, it is important to confirm beforehand the geology of the tunneling course ahead by a horizontal boring which starts in the cutting face.

With regard to the horizontal boring for the survey of the geology ahead of the face, CJRC is now engaged in technical development in order to largely improve the performance for the four elements; 1) long distance, 2) high speed, 3) directional control and 4) geological evaluation (Figs. 2 and 3).

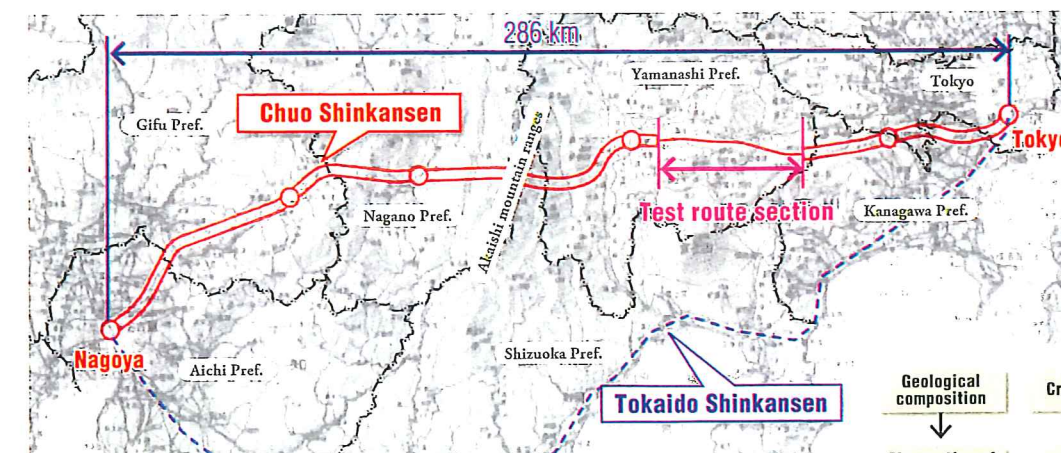


Fig. 1 Route map of the Chuo Shinkansen

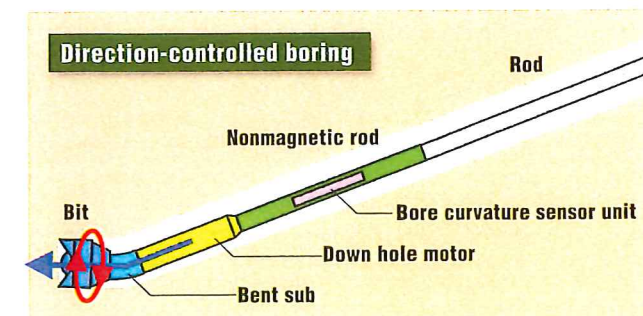


Fig. 2 Diagram of the boring direction control

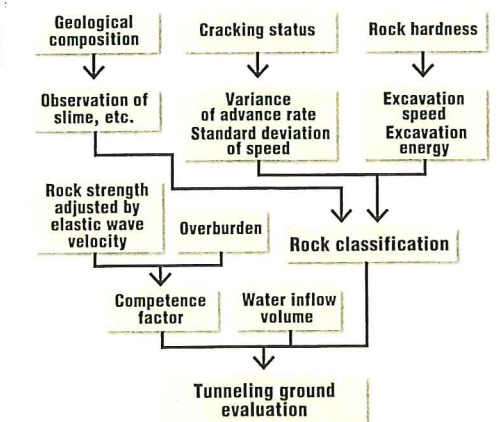


Fig. 3 Schema of tunneling ground evaluation by excavation data

# Large-scale Improvement of a Subway Line with Track Shift – Sannomiya Station on the Hanshin Electric Railway Line –

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Hanshin Electric Railway operates urban railway services over a total distance of 48.9 km including the main line between Osaka and Kobe, the major cities of west Japan.

## 1 Problems of the station Facilities

The Sannomiya station on this railway line, currently under improvement, is located at the center of Kobe where several transportation lines and commercial, service and cultural facilities are concentrated. This station is playing an essential role as one of gateways to the city. However, the station facilities are now faced with the following problems.

- 1) There is only one ticket barrier on the west side. It does not satisfy the requirement for two-way evacuation in the event of fire, mandatory for underground stations.
- 2) No elevator is installed, not meeting requirements for smooth movement.
- 3) It is not easy for passengers to get on and off trains that terminate and reverse at this station (turning back line). To solve these problems, the improvement project removes or enlarges the existing tunnel, constructs a new ticket barrier on the east side, provides elevators, and changes the cabling on the station premises.

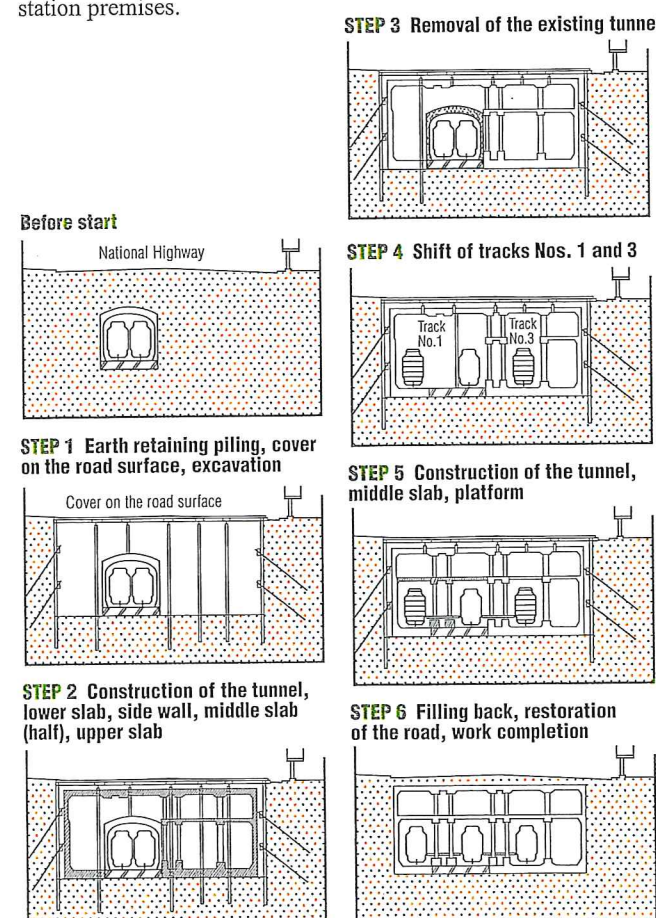


Fig. 1 Work sequence

## 2 Work sequence

The steps in the project are as follows (Fig. 1). Tracks will be shifted in four stages until work is completed (Fig. 2).

### 1) STEP 1 (completed in July 2011)

The turning back line was moved south, and the platform exclusively for disembarking was removed.

### 2) STEP 2 (completed in August 2011), Start operation of east ticket barrier (planned for March 2012)

The east section of the eastbound line will be moved north, the platform will be elongated, the middle floor constructed, and then the east ticket barrier will be put into operation.

### 3) STEP 3 (planned for summer 2012)

The track shift of the westbound line and turning back line will be shifted.

### 4) STEP 4 (planned for autumn 2012)

The west section of the eastbound line will be moved north, and the platform for disembarking of the eastbound line will be removed.

The work commenced in 2007, and the exit tunnel has been removed. The east ticket barrier is planned to be put into service in March. The project will be completed in the spring of 2013.

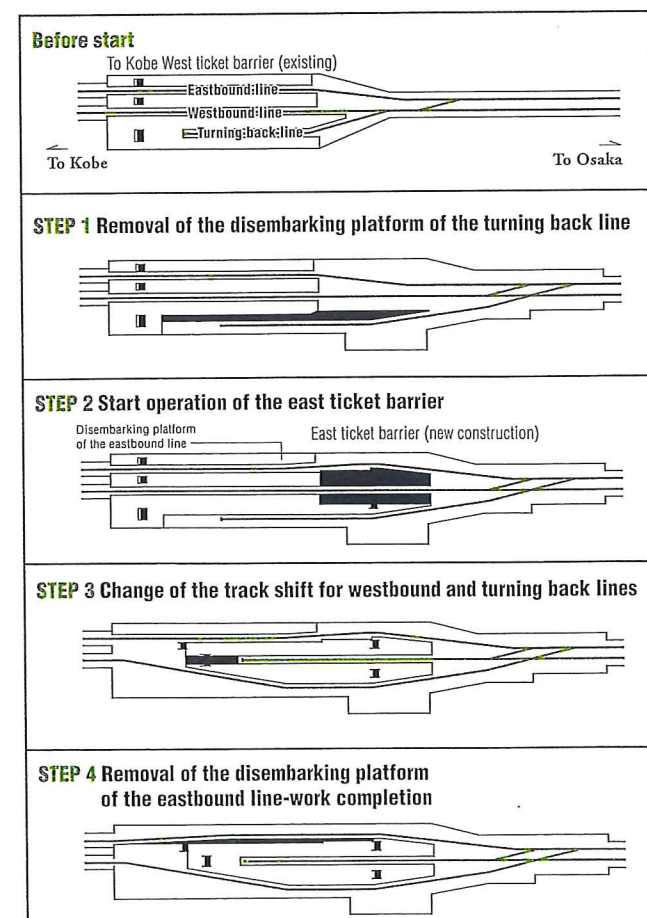


Fig. 2 Sequence of the track shift

# Mountain Tunneling close to an In-service Railway Tunnel – Shin-Kureha-Yama Tunnel on the Hokuriku Shinkansen Line –

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The Shin-Kureha-Yama tunnel on the Hokuriku Shinkansen line (“the new tunnel”) is a double track tunnel 440 m long, penetrating a hill mainly composed of alternating strata of Quaternary-Pleistocene sand clay, with overburden ranging from 3 to 25 m.

The new tunnel runs parallel with an in-service railway tunnel constructed more than one hundred years ago (“the existing tunnel”) (Fig. 1). Since adverse impact of the new tunnel construction upon the existing tunnel was anticipated, the soundness of the existing tunnel was investigated and impact was predicted by FEM analysis.

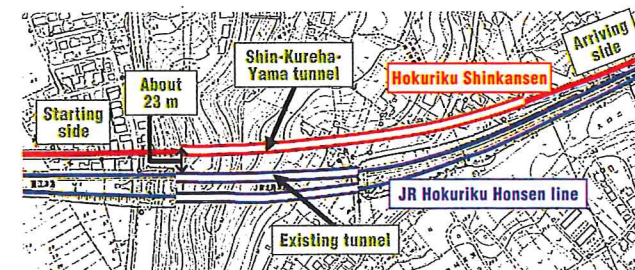


Fig. 1 Plan



Photo 1 Tunnel portals

## 1 Investigation of the existing tunnel soundness

Visual inspection and hammering test were conducted over the total length of the existing tunnel. No significant deterioration was found in the investigation. Next, from the results of the investigation, the soundness was evaluated in terms of performance including “stability of the tunnel structure” and “safety against spalling of the lining.” The investigation and the soundness evaluation demonstrated the fact that the existing tunnel was relatively sound as a whole.

## 2 Prediction of impact on the existing tunnel

The control reference value of convergence was set at 4 mm, based on the records of precedent tunneling projects. To assess possible impact of the new tunnel construction upon the existing tunnel, displacement was analyzed by FEM. This

analysis mainly evaluated displacement of the existing tunnel, induced by excavation of the new tunnel, to validate stability of the existing tunnel (Fig. 2). The FEM analysis predicted that maximum horizontal displacement of the existing tunnel toward the new tunnel would be 1.4 mm, and maximum vertical displacement (heaving) would be 0.7 mm.

Since the predicted maximum displacement was less than the control reference value and the existing tunnel was relatively sound, impact on the existing tunnel was expected to be small. No proactive measures were therefore taken, and the new tunnel construction was monitored for safety by measurement of convergence, width of cracking, and strain of the lining of the existing tunnel. The control reference value of convergence was set at 4 mm, based on records of precedent tunneling projects.

## 3 Results of construction

Excavation of the new tunnel started in June 2010, and breakthrough was safely achieved in December 2010. The maximum convergence of the existing tunnel caused by the excavation was 1.9 mm in the horizontal direction, which was near the predicted displacement.

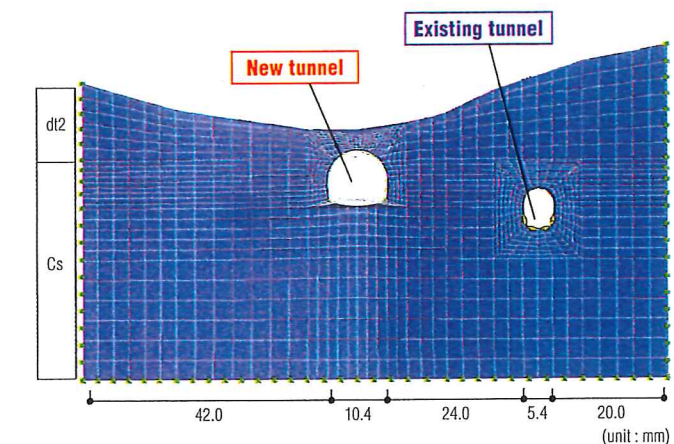


Fig. 2 Section of FEM analysis

# Large-section Shield Tunneling and Construction Methods for Shield Tunnel Expansion at Diverging/Merging Sections

– Metropolitan Expressway, Central Circular Shinagawa Route –

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The Central Circular Route of the Metropolitan Expressway in Tokyo, which will connect the radial expressway routes will help to disperse traffic in the metropolitan area. The Tokyo Metropolitan Government and the Metropolitan Expressway Co., Ltd., are jointly constructing the Central Circular Shinagawa Route (hereinafter referred to as “Shinagawa Route”), the last section of the Central Circular Route 9.4 km long, which is expected to be completed in 2013. For this project, we presented the basic requirements, invited technical proposals (including structural design and construction methods) and price proposals, and selected the successful bidder through a comprehensive assessment of the technical and price proposals.

## 1 Overview of the Shinagawa Route

Almost the entire length of the Shinagawa Route is underground, mainly under Yamate-dori Street, with some sections under the Meguro River (Fig. 1). Yamate-dori Street is heavily traveled, with numerous underground utilities. It also intersects 14 railways. These circumstances necessitated the adoption of the large-section shield tunneling method for most of the length of the Shinagawa Route, and construction work uses the most sophisticated state-of-the-art technologies.

### (1) Oi shield tunnel

A large-section shield tunnel with an external diameter of 13.6 m was built using a high-density slurry shield machine. The shield machine was started on the surface, and after constructing

underground structures, returned to the surface without needing a starting or an arriving shaft. For details, refer to page 26.

### (2) Main shield tunnel

A large-section shield tunnel with an external diameter of 12.3 m was constructed from the starting shaft in the vicinity of Oi Junction to the diaphragm wall in the vicinity of Ohashi Junction. The main shield tunnel is composed of two tubes, the clockwise tunnel and the counterclockwise tunnel. Both tubes with a length of 8 km were excavated using one high-density slurry shield machine each, without any midway shafts (Photo 1). In the course of work we have come up with various ways to deal with the issues involved in long-distance excavating. For instance, we devised a way to replace the cutter bit from inside the machine. The cutter bit is an important component that cuts the ground in front of the machine. Also, the slabs inside the



Photo 1 Shield tunnel (clockwise tunnel)

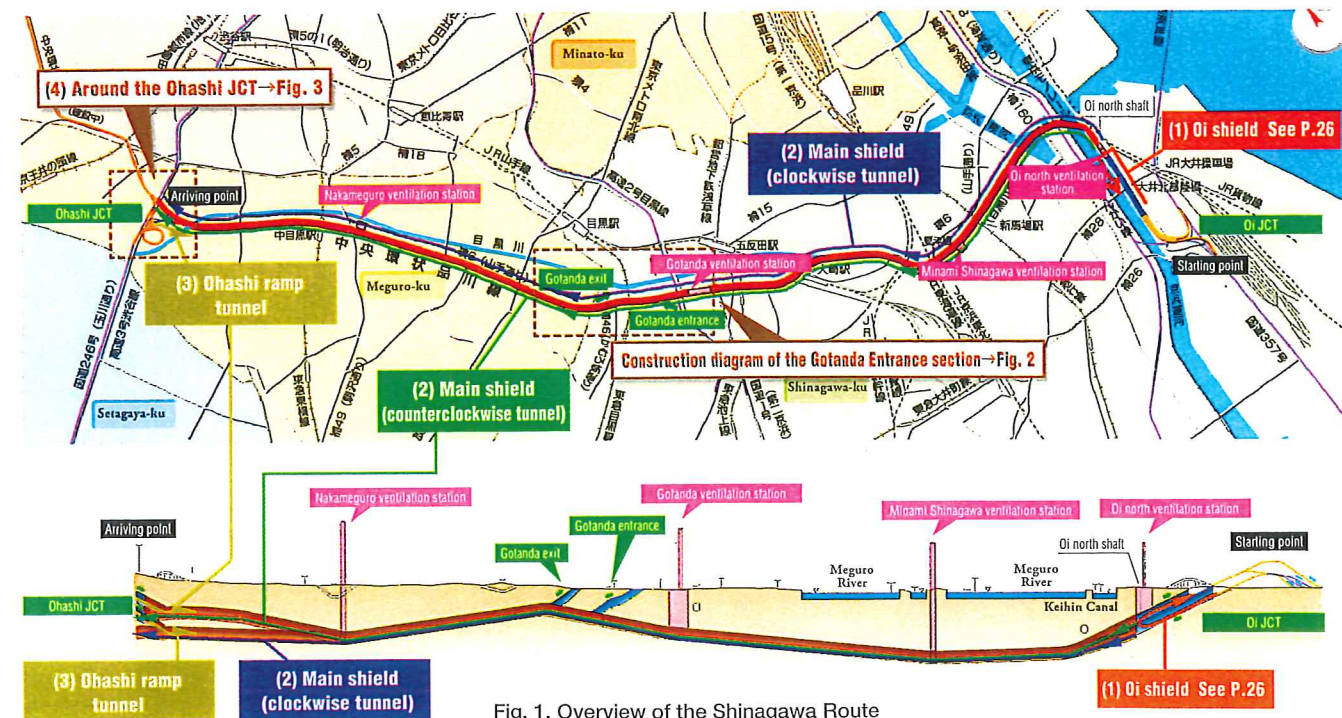


Fig. 1. Overview of the Shinagawa Route

tunnel were laid simultaneously with excavation. This method significantly reduced cost and construction time. After excavating the main tunnel, the diverging/merging sections of the Gotanda Entrance and Exit section will be built using the shield tunnel enlargement method (Fig. 2). We excavate the ground between the clockwise and counterclockwise tunnels using the cut-and-cover method (and the non-open excavation method under some intersections of streets), exposing parts of the main tunnel, and will build RC members of diverging/merging sections, which have rigid connections with the main tunnel. Next, we will remove some of the segments of the main tunnel, and the diverging /merging sections will be completed.

### (3) Ohashi ramp tunnel

The Ohashi ramp tunnel will link the Shinagawa Route with the Ohashi Junction loop, which is already in service. The Shinagawa Route will be connected through the Ohashi ramp tunnel with Route 3 (Shibuya Line). The section of the Ohashi ramp tunnel in the vicinity of the Ohashi Junction loop is built using the cut-and-cover method, and the end of the open-cut section was used as the starting shaft for the high-density slurry shield machine. From the starting shaft to the main tunnel, two tubes arranged vertically for the Ohashi ramp tunnel were excavated using the shield machine. The length of both tubes was approximately 500 m, and the external diameter was 9.5 m. After excavating the bottom tube, the outer shell of the shield machine was left behind, while the driving part was pulled out and transported back to the starting shaft, where it was re-used in the machine that excavated the top tube.

### (4) Construction of a tunnel connection in the vicinity of Ohashi Junction

The shield tunnels is enlarged at three locations in the vicinity of Ohashi Junction in order to build the diverging/merging sections (Fig. 3). The first location is the connection zone between the Shinagawa Route main tunnel and the Ohashi ramp tunnel (Expansion Zone A), where the diverging/merging section are built using the non-open enlargement method. The outer shell of the machine used in excavating the Ohashi ramp tunnel will

serve as the starting point for enlargement work. The NATM will be employed to excavate an arch-shaped tunnel between the main tunnel and the Ohashi ramp tunnel. Then, arch-shaped steel segments will be assembled between the two shields, and some of the segments assembled in the main and ramp tunnel will be removed later.

The second location is Enlargement Zone B, where construction work is carried out to enlarge the Ohashi shield, which is already in service, and connect it with the Shinagawa Route main tunnel. A section along the Ohashi shield with a length of approximately 200 m is excavated using a combination of the cut-and-cover method and the non-open excavation method, and RC members of expanded parts are built, which have rigid connections with the Ohashi shield. Special steel segments have been used in the construction of the Ohashi shield to make it possible to connect the shield with the RC members by working only outside the shield.

The third location was the connection zone between the Ohashi ramp tunnel and the Ohashi shield, which is already in service, in the vicinity of the Ohashi Junction loop (Expansion Zone C), where the tunnel is enlarged using the cut-and-cover method. Similar to Expansion Zone B, special steel segments have been used in the construction of the Ohashi shield in this zone, too.

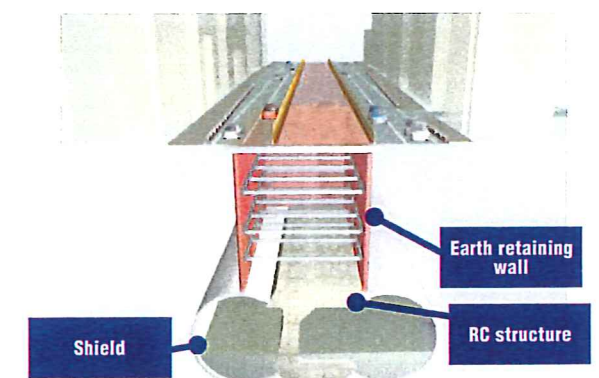


Fig. 2 Diagram of construction at the Gotanda Entrance/Exit section

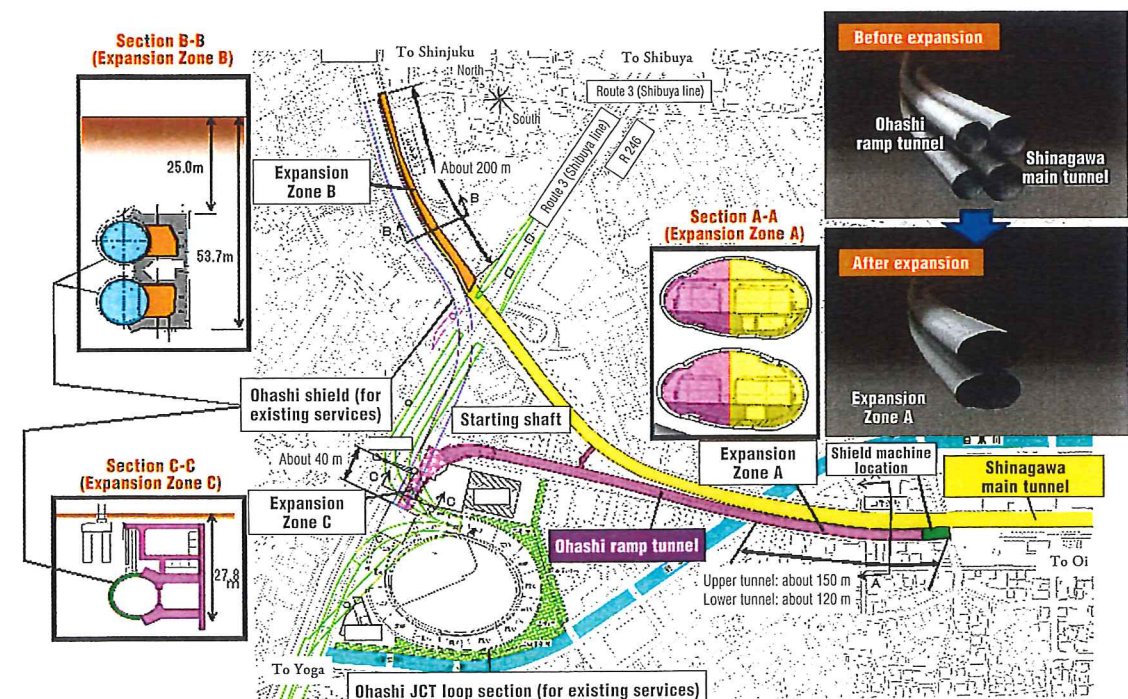


Fig. 3 Overview of the vicinity of Ohashi Junction

# Completion of Large-section Tunnels on the Shin-Tomei Expressway (Between Gotenba JCT and Mikkabi JCT)

Daisuke MARUYAMA

Construction Management Team,  
Construction Business Department, Tokyo Branch,  
Central Nippon Expressway Company

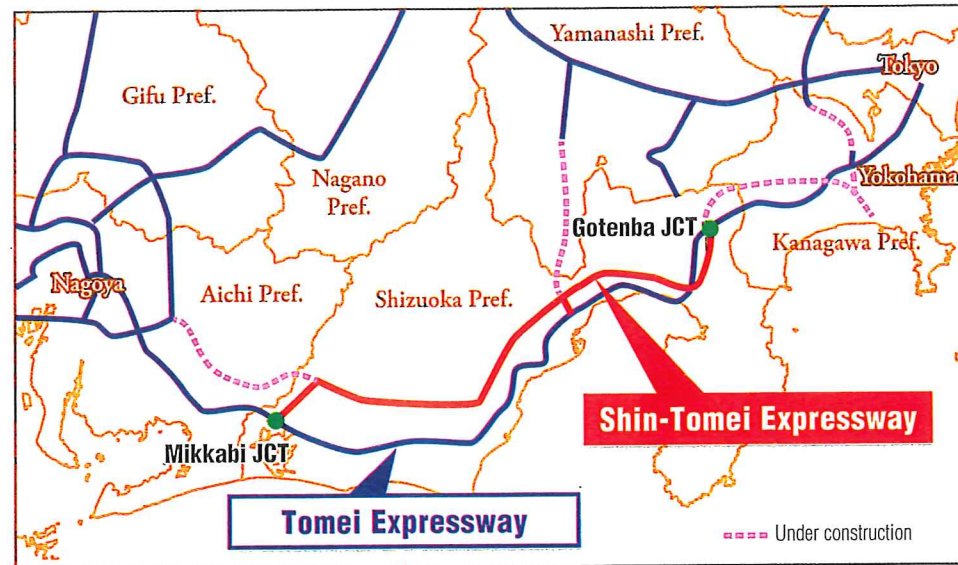


Fig. 1 Location

The Shin-Tomei Expressway (between Gotenba JCT and Mikkabi JCT) is a national expressway extending about 162 km located in Shizuoka prefecture as shown in Fig. 1. It is scheduled to be open for traffic on 14 April, 2012.

Since this sector of the expressway will alleviate traffic congestion on the Tomei Expressway running in parallel, help prevent disasters and enhance regional cooperation, it has been desired to open the route for traffic as soon as possible.

The Shin-Tomei Expressway passes through mountain areas. Accordingly, the ratio of bridges and tunnels on this expressway is higher than that of the parallel Tomei Expressway (Table 1). The tunnel ratio is especially very large, with a total of 71 tubes (83.3 km in total length) on the eastbound and westbound tunnels.

Table 1 Total length of the structures on the Shin-Tomei Expressway

	Tomei Expressway	Shin-Tomei Expressway
Total length of the sector *1	167.2 km	161.9 km
Bridge total length *1	24.5 km (14.7%)	51.0 km (31.5%)
Tunnel total length *1	5.6 km (3.3%)	42.0 km (25.9%)

\*1. These total lengths shown above are those for the westbound lanes.

## 1 Cross section shape of the tunnel

The tunnels of this sector have large cross sections with three lanes on each of the eastbound and westbound lanes, except for four tubes located on the routes linking the Tomei and Shin-Tomei expressways. The sectional area of excavation exceeds

180 m<sup>2</sup>, more than double compared with a conventional two-lane tunnel (about 80 m<sup>2</sup>) (Fig. 2).

In the study and design of the tunnel section, stability was analyzed, and as a result, the aspect ratio of the section was changed from the conventional value of about 0.65 to about 0.55. Thus a more flattened section was selected to reduce the excavation cross sectional area. In addition, high-strength supports shown in Table 2 were used to decrease the volume of shotcrete, rock bolts and steel arch supports, thereby reducing the cost.

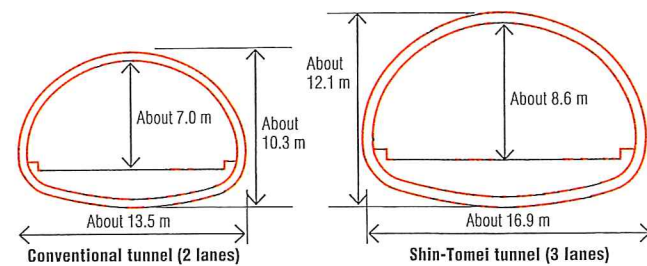


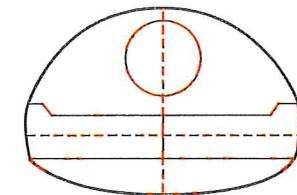
Fig. 2 Tunnel cross section

Table 2 High-strength supports

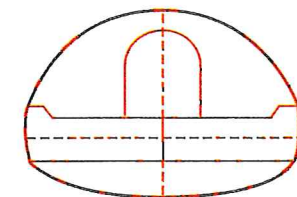
	Conventional	Shin-Tomei	Effects
Shotcrete	18 MPa	36 MPa	Reduce shotcrete thickness (from 200 mm to 150 mm)
Rock bolts	170 kN	290 kN	Reduce the number of rock bolts (from 30 to 21)
Steel arch support	400 kN	590 kN	Lighter weight

## 2 Excavation method

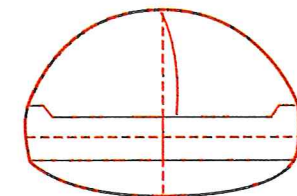
Since the excavation section is very large, the most essential point was to maintain stability of the crown and face. The stability of the face was achieved by optimal selection of excavation methods suitable for different geologies, using the TBM drift excavation followed by enlargement, central drift cutting followed by enlargement, and top heading with center diaphragm.



TBM drift with enlargement



Center drift with enlargement



Top heading with center diaphragm

Fig. 3 Examples of excavation methods used in the Shin-Tomei tunnel project

For long tunnels, the TBM drift with enlargement has been widely used (Photo 1). A TBM 5 m in diameter (Photo 2) enabled rapid drift cutting. It was possible to confirm ground conditions before the enlarging work, including cracking, degree of consolidation and water inflow. Moreover, based on the knowledge obtained in the drift excavation, the support patterns were determined, enabling the tunnel to be designed and enlarged efficiently and economically.

Of all the tubes in this sector, the drifts of 17 tubes 38.3 km long in total (about 46.0% of the overall length) were driven by TBMs. Although the TBMs were used in various geologies, rapid advance was possible without serious accidents. In adverse geological areas, the crown and face were reinforced in advance with cable bolts placed from the TBM drifts to satisfactorily produce the arch effect of the ground. All these measures contributed to safe and cost efficient construction of the tunnel tubes (Fig. 4, Photo 3)



Photo 1 TBM drift with enlargement

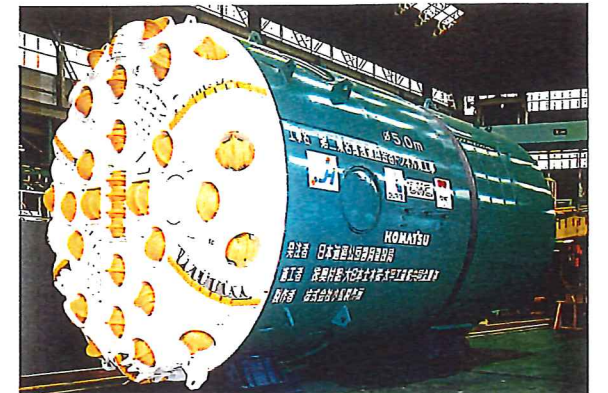


Photo 2 Tunnel boring machine

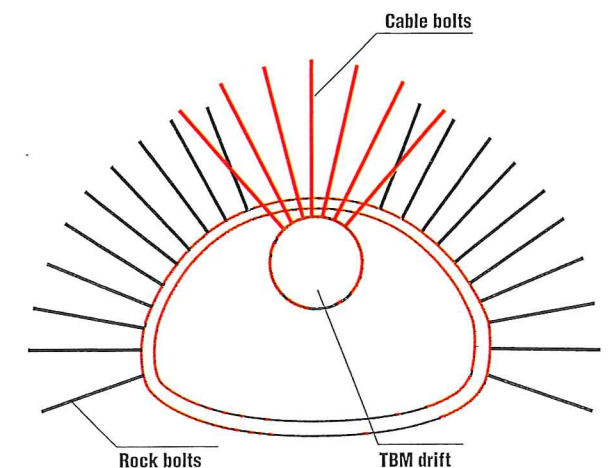


Fig. 4 An example of reinforcement in advance



Photo 3 Cable bolts

# Completion of Long Tunnels on the Hokkaido Transverse Expressway

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The Hokkaido Transverse Expressway is a national expressway stretching east to west through the Yubari Mountains and Hidaka Range near the center of Hokkaido. About 50% of the length of this expressway is in tunnels.

Expansive serpentine called Kamuikotan metamorphic rock is distributed widely, and there exists an extensive topography formed by large landslides. Since the sites of the Hobetsu and Shimukappu tunnels are located in especially weak geology, very challenging work was expected from the initial stage of the project. To cope with this problem, tunneling records around the site were analyzed, and countermeasures against landslides and high strength supports of the tunnels were studied from the design stage. As a result, the tunnels were broken through, overcoming the difficulties, in October 2011 as planned.

## 1 Early section closure and double support structure

The site of the Hobetsu tunnel is very weak, with a competence factor of about 0.2 and overburden about 400 m high. Considering such characteristics, the support structure of the main tunnel was designed on the basis of analysis using the measurement results of the evacuation tunnel bored before the main tunnel. The invert radius was set at 1.5 times as large as that of the top heading, that is, the section was nearly circular, and early section closure at about 10 m from the face (Photo 1) was planned. A double support structure with high-strength members was adopted to resist high squeezing earth pressures (systematically placing the secondary support after the primary support, as shown in Photo 1).

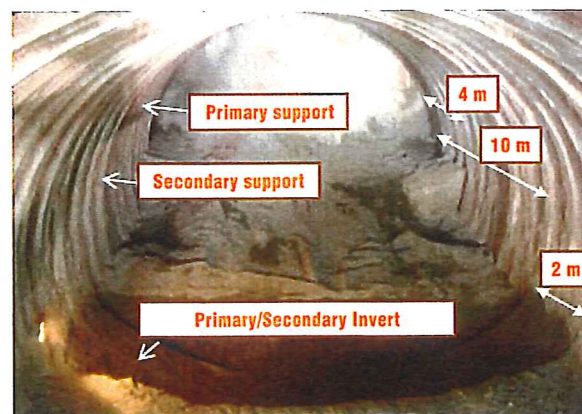


Photo 1 Early section closure

Since it was required to prevent the ground from loosening ahead of the face during excavation and to ensure stability of the surrounding ground, a large number of long steel-tube forepiling and long face bolts were driven, impeding the advance. To make up the delay, the number of main machines was doubled into a two-group system, and early-strength shotcrete (3 N/mm<sup>2</sup> at the age of 10 minutes, and 40 N/mm<sup>2</sup> at 28 days) (Fig. 1) was used, omitting the steel arch support on the secondary side. Since the geology of the Shimukappu tunnel site is similar to that of the Hobetsu tunnel, the double support structure was adopted again. However, because the ground near the foot of the upper half was weak, deformation occurred at the boundary of the lower half and invert. As a solution, the support structure was improved using lower-half/invert-integrated steel arch supports (Fig. 2).

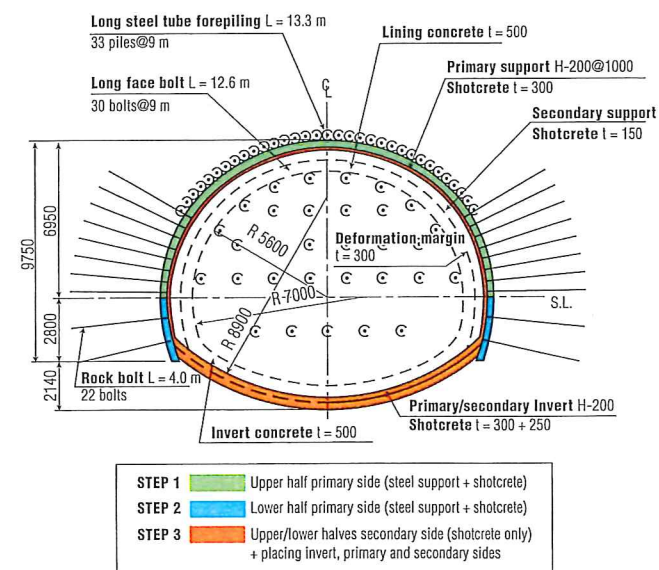


Fig. 1 Double support structure of the Hobetsu tunnel

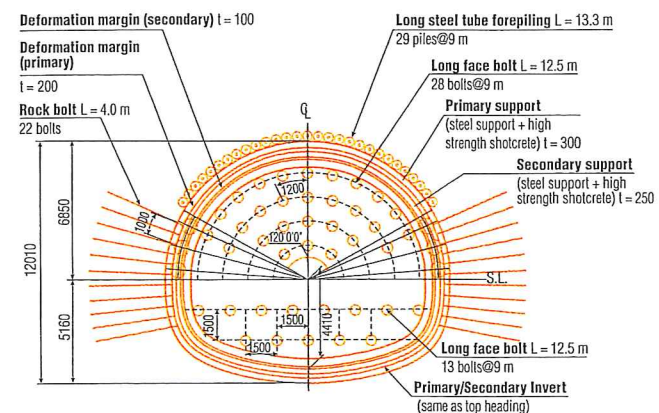


Fig. 2 Double support structure of the Shimukappu tunnel

# Tunneling in a Poor Geology Section under Plastic Earth Pressures, and Monitoring of the Lining after Completion

Yoshikatsu YOSHIDA

Former Manager of the Engineering Works Department (2nd), Fukushima Office of River and National Highway, Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

The Ozaso tunnel on the Tohoku Chuo Highway is a mountain tunnel 2,089 m long (77 m<sup>2</sup> in excavation section), located in the suburbs of Fukushima City. It was completed in February 2011.

## 1 Construction in a poor geology section under plastic earth pressures

Continuous brittle ground under plastic earth pressures was encountered, causing face collapse, convergence exceeding 150 mm and deterioration of supports. Measures taken to cope with this problem were upgrading of supports, additional bolting with water-expanded steel bolts, face bolting and early section closure with shotcrete invert (Fig. 1). These measures worked effectively to reduce the convergence rate of 35 mm/day to 0.4 mm/day. Moreover, a permanent invert was placed promptly to stabilize the tunnel structure. However, in the area where the measures were taken, quasi-hexagonal cracking occurred in many locations in some lining after displacement had converged. As a solution for this problem, galvanized steel fiber reinforced concrete was used for lining. This was the first attempt in Japan.

## 2 Monitoring of the lining for management and maintenance

In the area where the structural deterioration took place under plastic earth pressures, long-life optical fiber sensors were installed (Photo 1) to monitor stresses in the lining concrete.

## 3 Confirmation of structural deterioration after the earthquake

The earthquake off the pacific coast of Tohoku hit east Japan in March 2011. In the tunnel surroundings, it was 5.0 upper on the Japanese intensity scale. Even after the earthquake, there was no significant variation in stresses induced in the lining (Fig. 2), and no deterioration such as cracking was visually observed, demonstrating no abnormality in the area.

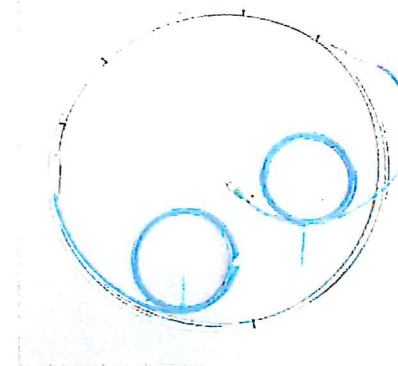


Photo 1 Optical fiber sensor

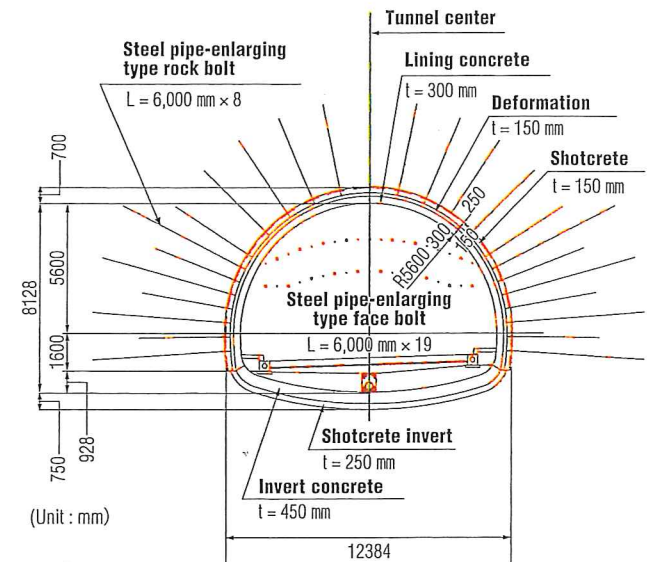


Fig. 1 DII section

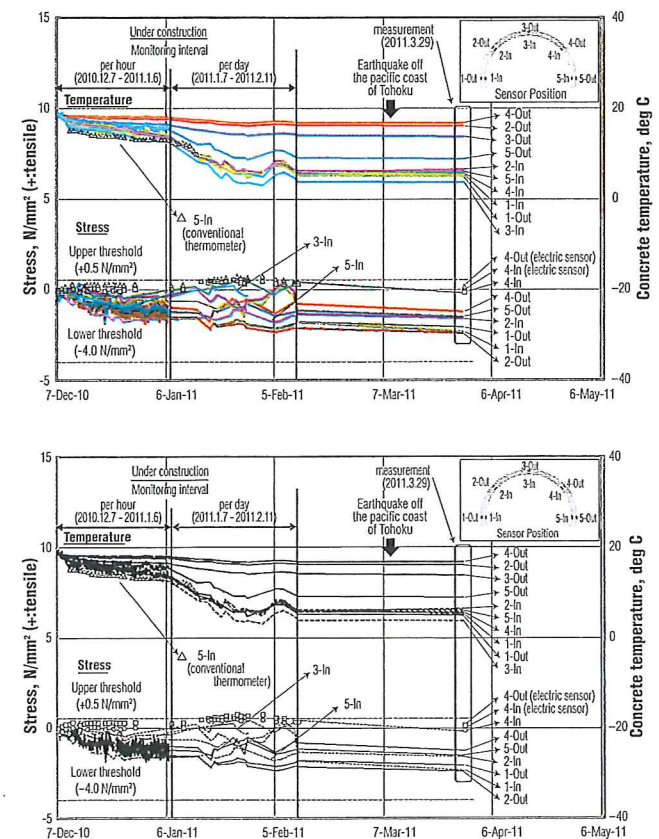


Fig. 2 Chronological changes in temperature and stress of lining concrete

# Observational Construction Practice of Early Section Closure

– Nanao Tunnel on the No-Etsu Highway –

Tsutomu MORIMOTO

Former Director, Kanazawa Office of River and National Highway, Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

The Nanao tunnel is on the No-Etsu highway in the Chubu district of Japan, 1,760 m long, with two lanes, 73.7 to 118.3 m<sup>2</sup> in excavation section. It was initially predicted that well consolidated sandy rock would lie all over the tunnel route. However, at 550 m from the portal, unexpected weathered tuff was encountered, increasing tunnel displacement. Therefore, the section was closed early to restrain deformation (Photo 1, Fig. 1).

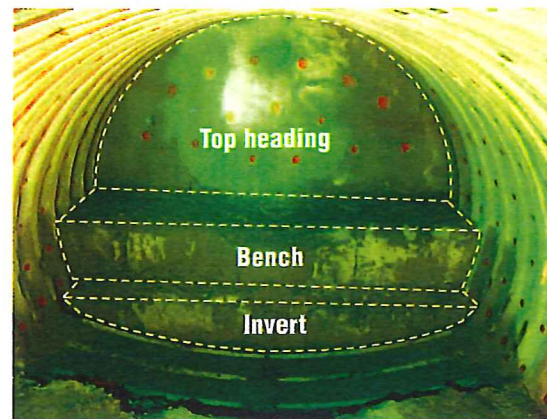


Photo 1 Division of heading

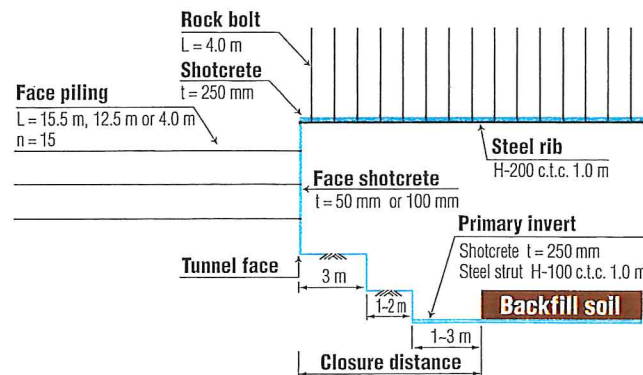


Fig. 1 Schematic diagram of excavation (longitudinal)

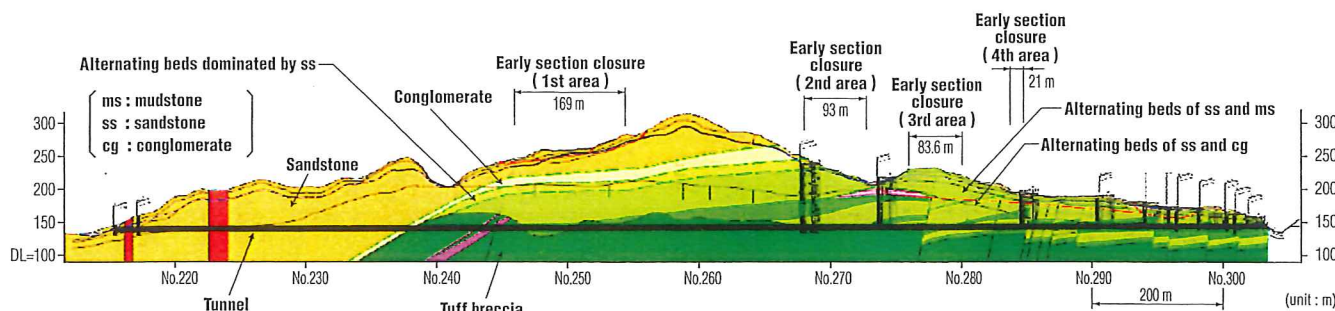


Fig. 2 Geological profile

\* Unexpected weathered tuff breccia appeared at the tunnel  
\* Tuff breccia : Anamizu Formation  
The others : Yatsuo Formation

## 1 Observational construction practice of early section closure

The geology of this tunneling site is ichanging irregularly and frequently, which caused significant variation of tunnel displacement. To cope with this problem, observational construction practice was selected. This method fully utilizes construction result data for subsequent work.

For this practice, selection criteria of specifications for early section closure were defined (Table 1), enabling prompt response to increase in tunnel displacement.

When setting up the selection criteria, priority was given to high strength shotcreting (36 MPa in design strength), aiming at more reasonable construction. It should be noted that, since steel struts are indispensable when encountering adverse geology, the reference values for placing steel struts were clearly defined in the selection criteria.

## 2 Construction results

In this project, the section was closed early in four locations (the length of this method was 366.6 m in total) (Fig. 2). The well-defined criteria made it possible to promptly change specifications in response to variation in geological condition. Consequently, tunnel displacement was effectively limited, achieving safe break through.

Table 1 Selection criteria for specifications

Ground condition	Pattern	Support				Primary invert				Closure distance
		Shotcrete	Steel rib	Shotcrete	Steel strut	Shotcrete	Steel strut	Shotcrete	Steel strut	
Good (Down-grade) / Bad (Up-grade)	1	250 mm	18 MPa	200×200 mm H-beam	400 MPa	250 mm	18 MPa	—	—	8 m
	2	250 mm	36 MPa	200×200 mm H-beam	400 MPa	250 mm	36 MPa	—	—	8 m
	3	250 mm	36 MPa	200×200 mm H-beam	400 MPa	250 mm	36 MPa	200×200 mm H-beam	400 MPa	6 m
	4	250 mm	36 MPa	200×200 mm H-beam	400 MPa	250 mm	36 MPa	200×200 mm H-beam	400 MPa	5 m
Criteria	[ Up - grade ]					[ Down - grade ]				
	1) Total amount of tunnel displacement Crown settlement : more than 40 mm Convergence : more than 80 mm					1) Total amount of tunnel displacement Crown settlement : less than 25 mm Convergence : less than 50 mm				
	2) Initial speed of tunnel displacement Crown settlement : more than 10 mm/day Convergence : more than 20 mm/day					2) Initial speed of tunnel displacement Crown settlement : less than 10 mm/day Convergence : less than 20 mm/day				
	3) Down in the JHR* distribution					3) Up in the JHR* distribution				
4) Initial speed of tunnel displacement after closure (Up-grade from pattern 2 to 3) Crown settlement : more than 5 mm/day Convergence : more than 5 mm/day					← Criteria for steel invert strut					

\* JHR means JH Method Rock Mass Rating System.  
In JHR, the most fine rock mass is 100 points, and the worst rock mass is 0 point.

# Tunnel Excavation in Ground Containing Heavy Metals

– Shin-Tomei Expressway Gakudozan Tunnel –

Makoto YAMAWAKI

Okazaki Nukata Construction Project Director, Toyota Construction Office, Nagoya Branch, Central Nippon Expressway Co., Ltd.

The Gakudozan Tunnel is a tunnel on the Shin-Tomei Expressway with a total length of 973 m (see page 12). The ground in that region contains large amounts of metamorphic rocks (gneiss), and the area of the Gakudozan Tunnel is composed predominantly of psammitic gneiss and pelitic gneiss. The preliminary survey confirmed that some of the metamorphic rocks in the vicinity of the tunnel contain heavy metals (lead, cadmium, arsenic, and selenium) at levels exceeding the national environmental standards.

## 1 Method for detection of heavy metals

There were concerns that the soil containing heavy metals might exceed environmental standards for elution amount, an indicator for solvability in water. That is why we continually tested the elution amount in the excavation muck. The testing was conducted using a voltammetric method, in which electrodes were submerged in a liquid solution and the electric potential and the current were measured. The obtained data was used for qualitative and quantitative analysis of dissolved matter (Photo 1).



Photo 1 Voltammetric measurement device

## 2 Countermeasures

Initially the muck with the heavy metal levels above the standard was transported to a commercial disposal site. Soon, however, the volume of such muck exceeded the projections, reaching about 80% of all muck, so the plan was changed to use the muck for embankment of the expressway. Special measures were taken to prevent soil containing heavy metals from contacting rainwater by building an impermeable layer around it (Fig. 1). After constructing a concave embankment with soil conforming to the environmental standard, bentonite clay and impermeable sheets were placed to form a base (Photo 2). Next, the concavity

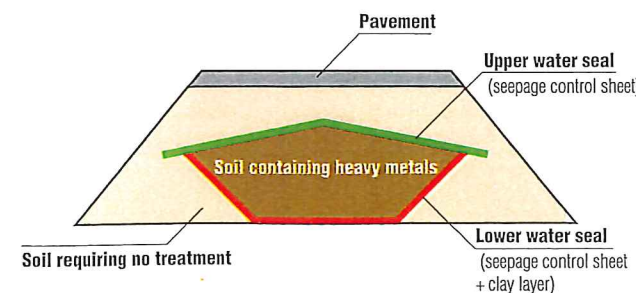


Fig. 1 Structure of an embankment to deal with soil containing heavy metals

was filled with muck containing heavy metals and then covered with impermeable sheets (Photo 2). The effect was confirmed by keeping the storm sewer in the muck containing heavy metals.



Photo 2 A layer of impermeable sheets

## 3 Status of construction work

The testing of the elution amount requires approximately 10 hours, so the muck was temporarily set aside. A large tent was set up in the yard where the muck was temporarily stored to protect them from rain (Photo 3). Prior to starting work, we repeatedly held explanatory meetings for residents over half a year, and succeeded in obtaining their understanding. Soil containing heavy metals was discovered in two tunnels, so excavation was suspended in one of the tunnels to reduce the muck volume till embankment preparation. This tunnel was used as a temporary storage for muck (Photo 4). During embankment, we surveyed water quality around the site, and showed the survey data to residents, thus generating a feeling of security. Furthermore, we dispatched an adsorption device for heavy metals as a contingent measure. After completion of embankment, we will monitor the quality of groundwater in the area for two years according to relevant legislation.



Photo 3 Large tent for storing excavated muck



Photo 4 Temporary storage of excavated muck in the tunnel

# Extremely Large-section Tunneling in Unconsolidated Shirasu

– Shin-Takeoka Tunnel on the Route 3 Bypass –

Nobuyuki GOTANDA

Manager of the Engineering Works Department(2nd),  
Kagoshima National Highway Office  
Kyushu Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism

The Shin-Takeoka Tunnel is a mountain tunnel 1,500 m long (Fig. 1). This tunnel branches into two tunnels underground. The sectional area of part A is extremely large, 380 m<sup>2</sup> in excavation section and inner section 245 m<sup>2</sup> (Fig. 2).

## 1 Geology

The geology of the tunneling site is Shirasu that is non-welded part of pyroclastic flow deposit of about 25,000 years ago, highly homogenous and slightly consolidated. This type of geology presents relatively good ground stability. The unconfined compressive strength is around 20 to 100 kN/m<sup>2</sup> (0.02 to 0.1 MPa). With a large overburden (more than 50 m), the cutting face became unstable, and Shirasu ground beneath the ground water was washed away, and ground stability was lost.

## 2 Excavation of the extremely large-section tunnel

The extremely large-section part in the Shirasu was excavated by the side drift method. The tunneling sequence is shown in Fig. 3. In the top heading, forepiling and face bolting were performed to stabilize the crown and the face. Since, in the extremely large-section part, ground water was at 2 m above the invert, well points were driven from the top heading invert of the side drift, then the bottom section was excavated. Side wall concrete placed in the side drift method enabled maximum possible use of load bearing capacity of the surrounding ground, limiting settlement at the top heading foot to 4 mm and crown settlement to 30 mm. Thus the stability of tunneling was maintained.

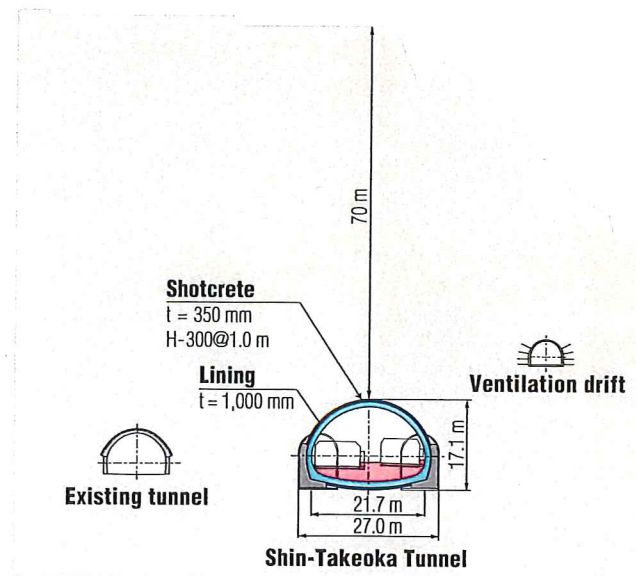


Fig. 2 Tunnel cross section

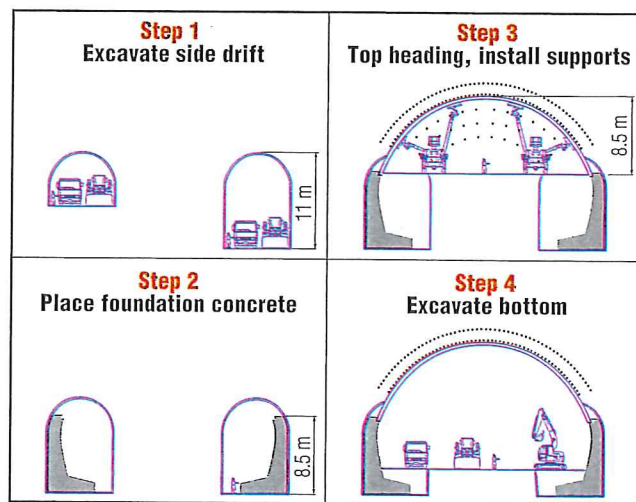


Fig. 3 Tunneling sequence

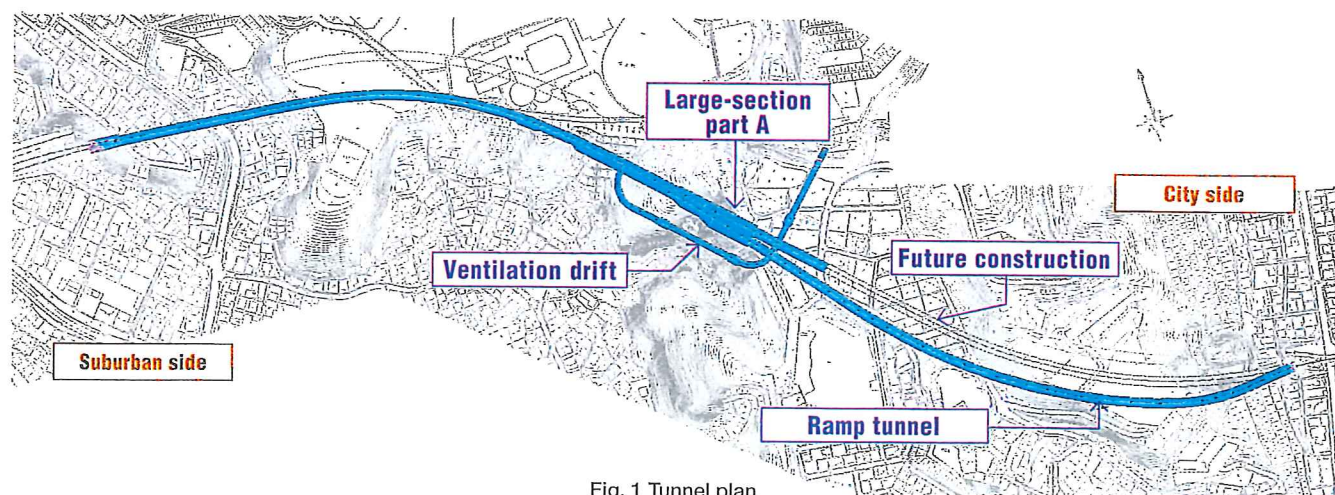


Fig. 1 Tunnel plan

# Cut-and-cover Tunnel through a Densely Congested Area

– Construction of the Hanshin Expressway Kobe-Yamate Route (South Extension) –

Toru TAKAISO

Chief, Kobe Business and Maintenance Department,  
Hanshin Expressway Company Limited

The Hanshin Expressway Kobe-Yamate route passes along a river in a densely congested area. Almost the entire route is in a cut-and-cover tunnel. Since this route crosses or passes near three railway lines, major roads and underground utilities, it had to be built under difficult conditions with strict limitations.

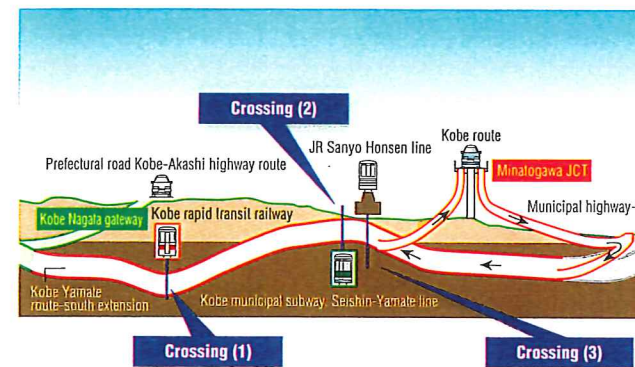


Fig. 1 Longitudinal section

## 1 Technological features of the structure crossing the railway

- Crossing (1)

In this section, the expressway route crosses just below the existing railway tunnel. The railway tunnel was temporarily underpinned with steel tube piles, and an expressway tunnel was constructed below (Fig. 2). The railway tunnel crosses the expressway tunnel at an angle of about 30 degrees, which resulted in massive underpinning work. The total length of the temporary underpinning was 120 m, the total weight was 200,000 kN, and the number of the steel tube piles was 96. The underpinning was maintained for 6 years. Displacement of the railway tunnel was minutely controlled with 120 jacks.

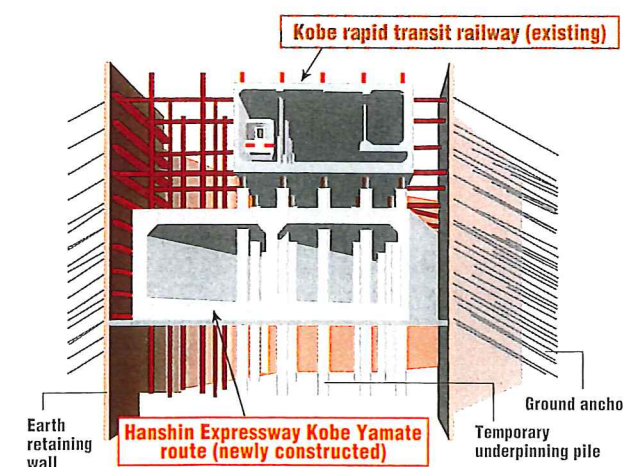


Fig. 2 Crossing with the Kobe Rapid Transit Railway

- Crossing (2)

The expressway tunnel was constructed 70 cm just above the subway tunnel (Fig. 3). It was anticipated that cut-and-cover work would adversely impact the subway tunnel, because of rebounding of the excavation bottom. Therefore, analysis by the FEM was made in advance. Based on the analytical results, impact on the existing subway tunnel was reduced, by stepped lowering of the excavation bottom and lowering of groundwater level, etc.

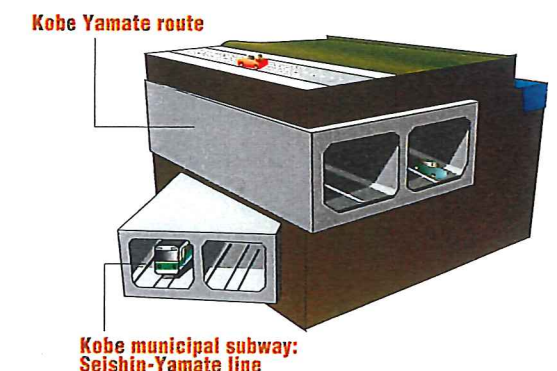


Fig. 3 Crossing with the Kobe municipal subway

- Crossing (3)

The expressway tunnel was constructed just below the five tracks of JR lines with quadruple tracks and a freight track (Fig. 4). Work beams were erected and underpinning piles were driven. In addition, temporary support beams were inserted from the side, to support the five tracks, then the ground was excavated to construct the expressway tunnel. After the load was carried by the top slab of the expressway tunnel, instead of the temporary support beams, the temporary underpinning piles were removed.

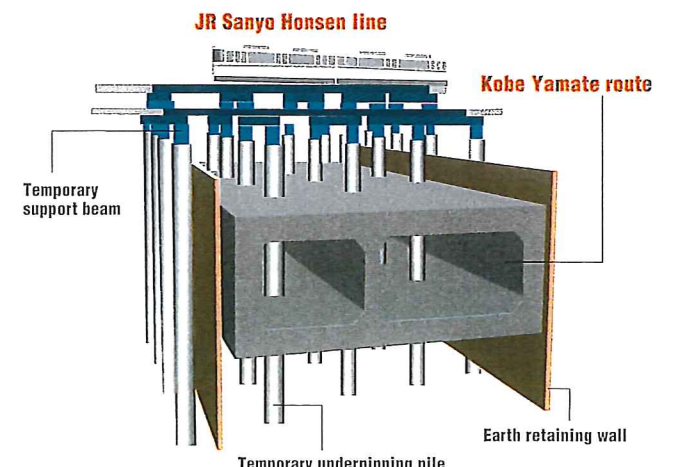


Fig. 4 Crossing with JR Sanyo Honsen Line

# Tunneling with Continuous Belt Conveyor

– Scour Tunnel for the Koshibu Dam –

Masaru TAKAGI

Director, Tenryugawa Integrated Dam and Reservoir Group Management Office, Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

The Koshibu dam is a multipurpose dam completed in 1969, for flood control, irrigation and power generation. This project is to construct a scour tunnel linking the upstream side of the dam reservoir with the downstream side of the dam. This tunnel reduces soil inflow and sediment in the reservoir, thereby maintaining the effective capacity of the dam.

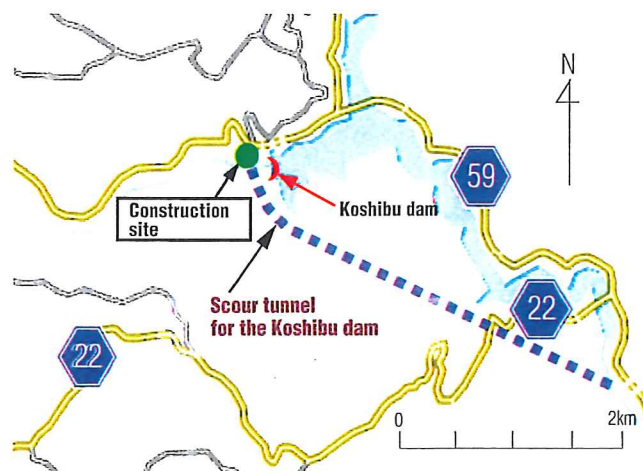


Fig. 1 Location of the scour tunnel

## 1 Construction planning

This project is the fourth scour tunnel in Japan. The inner section is 48.7 m<sup>2</sup>, equivalent to a road tunnel with one-lane on each side. However, to ensure regular flow of soil, the tunnel has a smaller width and a greater height (Fig. 2). It is a long tunnel, about 4 km. Since the intake on the upstream side is lower than the riverbed, there was a risk of flooding in the tunnel under construction. Therefore, the tunnel is being excavated in a single direction with a longitudinal gradient of 2% from the downstream discharge side. The tunneling technique used is the NATM by full-face blasting and cutting, with auxiliary bench. The geology is granodiorite of about 100 MPa in unconfined compressive strength.

Under the circumstances, because of the large length and small width of the tunnel, it would be difficult for dump trucks (20 t) and truck mixers to pass each other in the tunnel. Considering

this problem and for improving safety in the tunnel and ease of excavation, mucking with a continuous belt conveyor was planned (Fig. 3, Photos 1 and 2). The belt conveyor is 750 mm wide and the capacity of the crusher is 300 t/h.

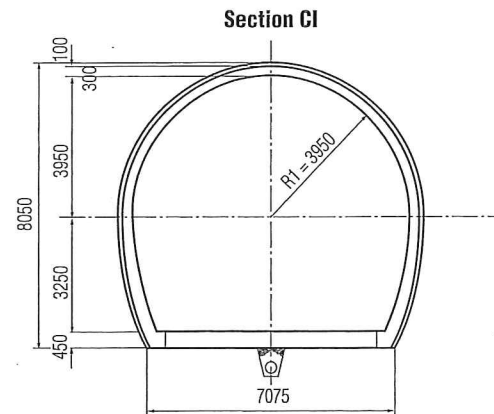


Fig. 2 Standard cross section (in mm)

## 2 Tunneling performance

Tunneling with mucking by the continuous belt conveyor started on March 4, 2010. Of the completed length, the section excavated with the continuous belt conveyor was 2,723 m. The monthly advance was 136 m on the average and 172 m at maximum. The remaining length is about 700 m. Tunneling is underway, aimed at breakthrough in April 2012.



Photo 1 Belt conveyor outside the tunnel



Photo 2 Continuous belt conveyor in the tunnel

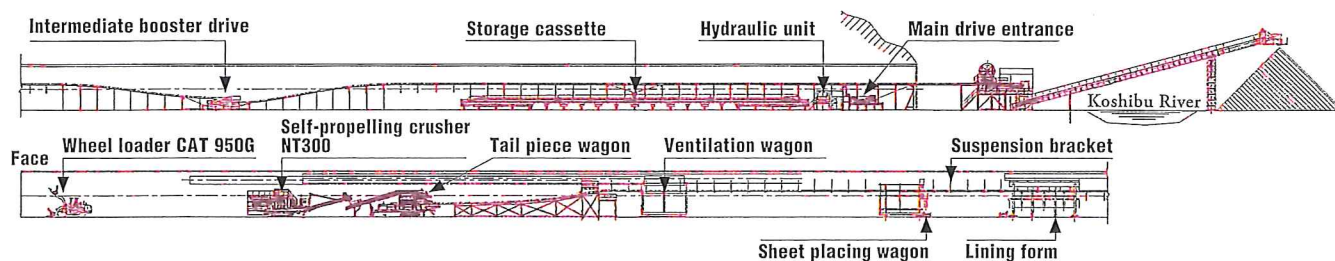


Fig. 3 Arrangement of the continuous belt conveyor

# Excavation of Long Penstock Inclined Shafts with TBMs

Kohei UCHIDA

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The Omarugawa hydro power plant is a pumped-storage type facility, linking the upper and lower regulating basins via a water channel about 2.8 km long, with an effective head of 646.2 m, outputting 1,200 MW at maximum. The penstocks (Nos. 1 and 2) between the upper regulating basin and underground plant are 6.1 m in diameter, 888.7 m long, with a gradient of 48 degrees. Two TBMs were used for excavation for the penstocks. The geology is alternating strata of sandstone and shale, crossing the inclined shaft at nearly right angles, with a fractured zone crossing the same shaft in one location (Fig. 1).

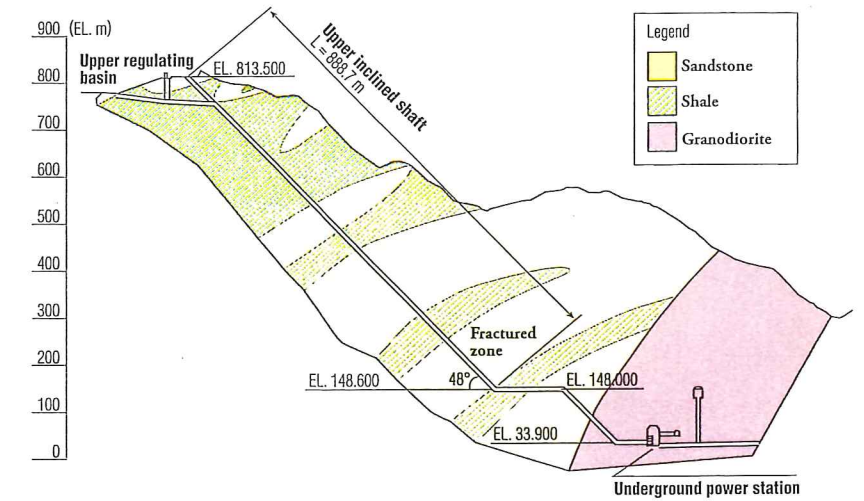


Fig. 1. Geology profile

## 1 Construction method

The inclined shaft was constructed as follows:

First a drift was driven through from bottom to top with a 2.7 m diameter TBM (drift TBM), then the drift was enlarged with a 6.1 m diameter TBM (enlarging TBM) from top to bottom. The drift was used for mucking during the enlarging excavation. The drift TBM was equipped with shield jacks and shield shells (full shield type), to enable cutting even in the fractured zone where reaction of grippers was not available. In order to prevent the drift TBM from sliding down, an invert liner that can be cut during enlarging excavation was developed to improve safety and shorten the construction period. The enlarging TBM was an open type with a cutter sliding on the main beam. After the drift was broken through, the weak geology zone was improved by grout injection, rockbolts and lining concrete, to stabilize the ground during enlarging excavation.

## 2 Work results

The construction period plan was about 9 months for drift excavation and about 10 months for enlargement excavation, including one month of the initial advance period for sequentially connecting the tail equipment items to the TBMs. For penstocks No. 1 and No. 2, the drift was completed almost as planned, and the enlarging was completed ahead of schedule. After excavation of the inclined shaft was completed, the penstock iron pipes were installed, and concrete filling was performed. Use of No.2 penstock started in July 2007 and No.1 from July 2010 for power generation.



Photo 3 Cutable invert liner

Table 1 Specifications of the drift TBM

Specifications	Shape and dimensions
Type	Shield
Excavation diameter	2,700 mm
Machine length	8,020 mm (including trailing carriage 60,590 mm)



Photo 1 Drift TBM

Table 2 Specifications of the enlarging TBM

Specifications	Dimensions
Type	Open type (with sliding cutter)
Excavation diameter	6,110 mm
Machine length	12,000 mm (including trailing carriage 42,000 mm)

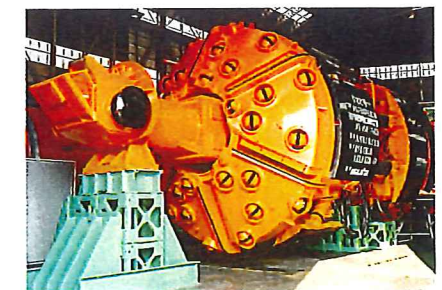


Photo 2 Enlarging TBM

# Rapid Construction of a Long Shield Tunnel Crossing below a Seabed

— Gas Pipeline Installation under the Ise Bay —

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Tetsuji **KITANO**

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Chubu Electric Power and Toho Gas are jointly installing a gas pipeline crossing the Ise Bay. The tunnel for the pipeline is composed of two sections: section I 3.0 m in inner diameter, 13.3 km long, and section II 2.0 m in inner diameter, 4.0 km long (Figs. 1 and 2). Both sections are long shield tunnels under the seabed. Section I is bored with two shield machines from both banks to keep within the specified work period, and the two shields are joined underground below the seabed using the freezing method. The tunneling in section I is described below.

## 1 Planning

About 70 percent of the ground bored by the shield machines is composed of cohesive soil with N-value of 0 to 4 and sandy soil with N-value of 0 to 18. However, on the Chita shaft side, an alternating stratum of consolidated silt, gravel and sand, with N-value of 50 or more, was predicted to lie over about 2 km (Fig. 3 showing the predicted longitudinal geological section). To make the structure maintenance-free, the tunnel interior was planned to be charged with filler after installation of gas pipes. For rapid construction, this project adopted wide reinforced segments (1,350 mm wide), each ring being composed of six equal reinforced concrete segments, and a pin joints enabling assembly only by pushing segments in the tunnel axis direction with the erector. This project used a slurry shield suitable for long distance tunneling exceeding 6 km, under high water pressures of 0.4 MPa, underground docking and rapid advance.

## 2 Performance of the tunneling

The average progress was 701m per month on the Kawagoe shaft, and 644m on the Chita shaft side. The machine relative deviation at the final coupling was -9 mm horizontal and +1 mm vertical.

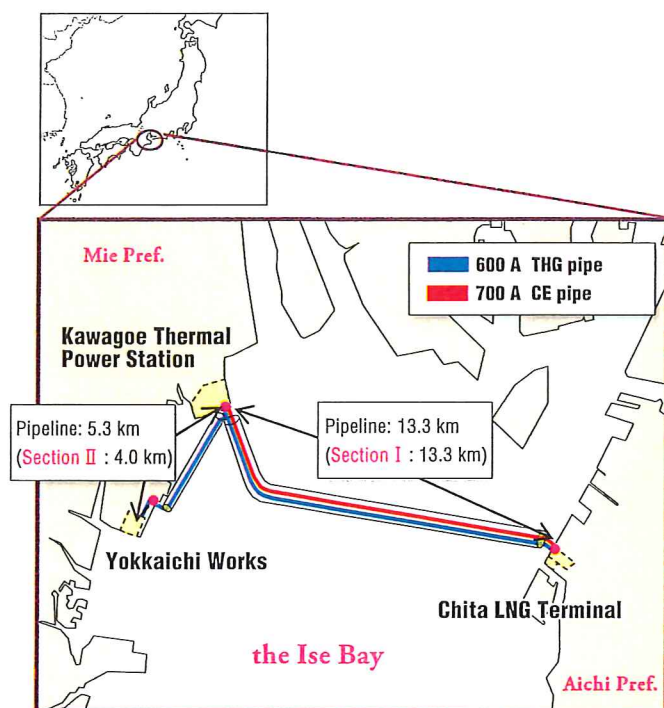


Fig. 1 Tunnel alignment

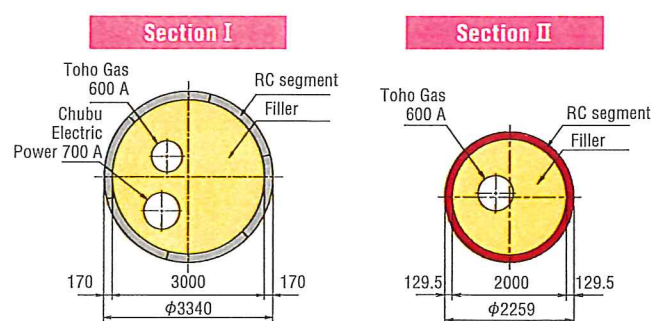


Fig. 2 Cross section of the tunnel

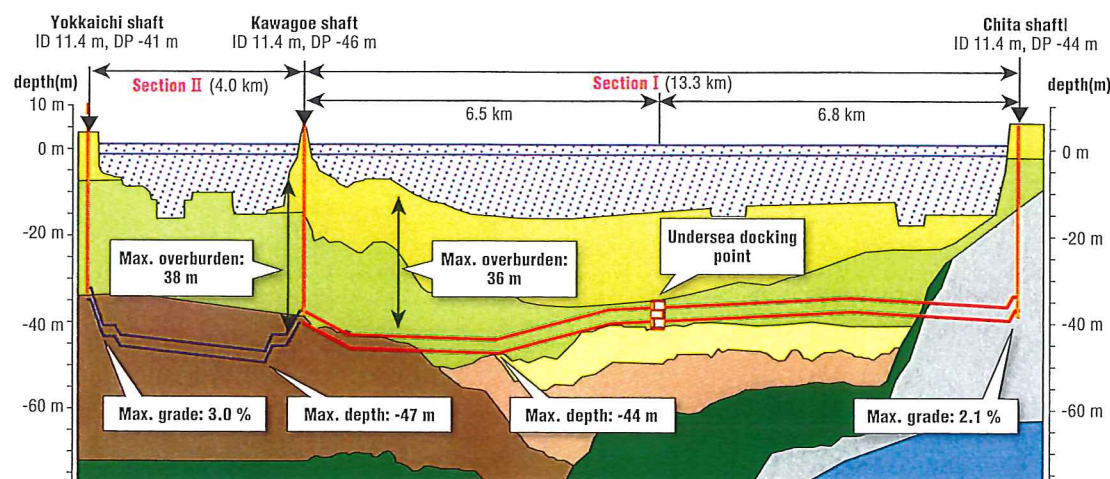


Fig. 3 Longitudinal section of the pipeline and geology (red line: section I route, blue line: section II route)

# The First Test Facility in Japan for Verifying High-pressure Natural Gas Storage

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Shimizu-Obayashi-Taisei Joint Venture

In the technical development of the ANGAS (Advanced Natural Gas Storage), a rock cavern for the verification test facility, the first one in Japan, was constructed in the Kamioka mine under the direction of Japan Gas Association (Fig. 1). This site is located about 3 km from the Super-Kamiokande famous for winning the Nobel Prize (neutrino). It is a small test facility in a special shape with composite equipment, capable of validating pressure resistance and gas tightness under high pressure of 20 MPa (volume of the facility=240 m<sup>3</sup>, storage capacity=48,000 m<sup>3</sup>, equivalent to a gas holder about 25 m in diameter).

The basic concept of commercial facilities in the scope of the ANGAS technology development is as follows:

- (1) Pressure resistance is supplied by the surrounding bedrock. (Inner pressures are transmitted to the surrounding ground via backfilling concrete. The bedrock resists high pressures)
- (2) Steel plates are used to ensure gas tightness.
- (3) A water drainage system prevents excessive external pressures from acting on the gas-tight steel lining during construction and when inner pressures are released.

This cavern was constructed by the drill and blast method, with overburden about 400 m high in sedimentary rock of the Kamioka mine. Commercial facilities are expected to be constructed in urban neighborhoods, where sedimentary rock geology is relatively common. This was the why sedimentary rock was selected for the site of the verification test facility.

## 1 Construction

The layout of the bedrock storage tank of this test facility is shown in Fig. 2. Unlike silos for commercial facilities, the storage tank is in the shape of medicine capsule placed horizontally. The gas-tight steel plates are SM400, and the standard section is 6 mm thick.

After an access tunnel was excavated, the plug and storage sections were constructed by advanced drift drilling followed by enlargement. This work was performed with utmost care, with work stages divided as shown in Fig. 2. Photo 1 shows the view

after the excavation of the bedrock storage tank. The wall was lined with shotcreting. The black lines in the grid are drainage pipes, measuring cables and optical fibers of measuring instruments. For verifying the pressure resistance of natural bedrock, a site was selected with geology mainly composed of CH to CM classes (according to the bedrock classification by the Central Research Institute of Power Industry). The cavern was constructed by the NATM with shotcrete (100 mm thick) and rockbolts (D25, 3 m long, 16 bolts/section) placed immediately after excavation.

Next the gas-tight steel plates were assembled and welded, and backfilling concrete was placed, and the plug and manhole were installed. Photo 2 shows the verification test facility after completion of the entire storage tank.

It took about three years to complete the project including survey, preliminary test, construction, disassembling and closure.

We are planning to continue technological development, aimed at further cost reduction and more reasonable design and construction, to build commercial storage facilities.

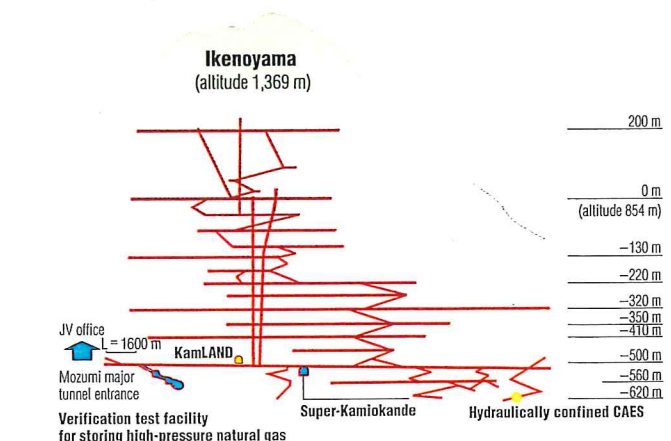


Fig. 1 Location of the facility

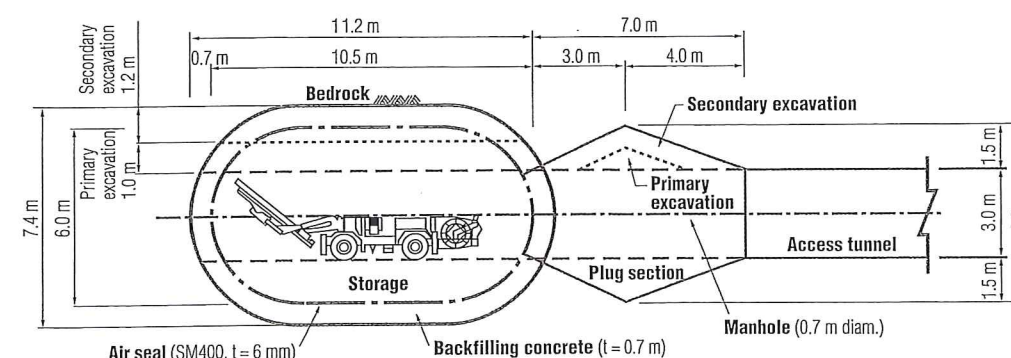


Fig. 2 Overall structure of the test cavern and excavation diagram



Photo 1 Inside of the storage tank after excavation



Photo 2 Completed entire facility

# URUP, Shield Tunneling Technique that Enabled Start and Arrival on the Surface, First in Japan

– Oi Area Tunnel on the Central Circular Shinagawa Route –

**Kouji GOTO** Section Manager, 2nd Construction Office, Tokyo Metropolitan Government

The tunneling in Oi area on the Central Circular Shinagawa Route is a project to construct the connection from the Oi junction viaduct branching from the Bay-shore route to the through-lanes in a tunnel on the Central Circular Shinagawa Route.

The construction included a twin motorway tunnel (two lanes each) and the underground portion of Oi north ventilation station.

## 1 Features of the project

Since the site geology is weak and there are many structures in the proximity, various technical proposals were solicited, principally aimed at reduction of excavation volume. Consequently, the plan using the URUP developed by Obayashi Corporation was selected.

The technique named URUP (Ultra Rapid Under Pass) needs no starting or arriving shaft. The shield machine is started on the surface, and after constructing necessary underground structures, returns to the surface. The present project used this method for constructing the approach to the tunnel from the surface, for the first time in Japan.

This was a challenging project that constructed a tunnel 13.4 m in outer diameter consisting of a preceding tube 550 m and succeeding tube 336 m in length (Fig. 1), with one of the largest high-density slurry shield machines in the world (Photo 1).



Photo 1 Before start on the surface (Machine setting completed)

The use of the URUP significantly shortened the on-site work period, compared with the open cut tunneling initially

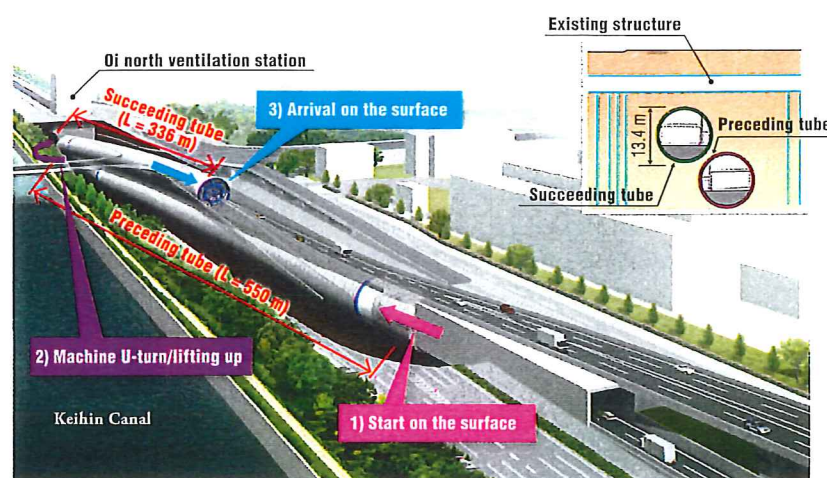


Fig. 1 Overview of the project

expected. Furthermore, since the shield tunneling excavated only the section necessary for the structure, the excavation volume was reduced by about 40% and CO2 emission was cut by 57%, calculated from the reduction of excavation machines and transport vehicles.

## 2 Construction close to existing structures

The structure in the proximity that posed the greatest problem in this project was a power transmission tunnel. It is a shield tunnel 2.4 m in outer diameter, an important structure crossing the present project at right angles.

The URUP shield had to pass a mere 400 mm from the power transmission tunnel. To cope with this problem, measures were taken, such as protection by ground improvement and information-oriented construction, and stringent control of earth pressure on the face for tunneling with shallow overburden featuring the URUP method. These measures worked well to enable the shield machine to pass through without causing impact on the power transmission tunnel.

## 3 Conclusions

The shield machine started on the ground in March 2010 (Photo 2) and arrived on the ground in May 2011 without adverse impact on the surrounding ground or existing structures (Photo 3) This project demonstrated the effectiveness of the URUP, an unprecedented technique that does not need either starting or arriving shaft, enabling successful tunneling extremely close to important structures.



Photo 2 Start on the surface



Photo 3 Arrival on the surface

# Tunnel Disaster Earthquake off the Pacific Coast of Tohoku, 2011

**Toshihiro ASAKURA** Professor of Kyoto University

## 1 Earthquake and damage in brief

At 14:46, March 11, 2011, an earthquake of moment magnitude (Mw) 9.0 occurred, with the hypocenter at a depth of 24 km about 130 km east off coast of the Tohoku district. The main shock of the earthquake measured an intensity of 6 upper on the Japanese scale in a wide area of Tohoku, with the maximum intensity of 7 (Fig. 1).

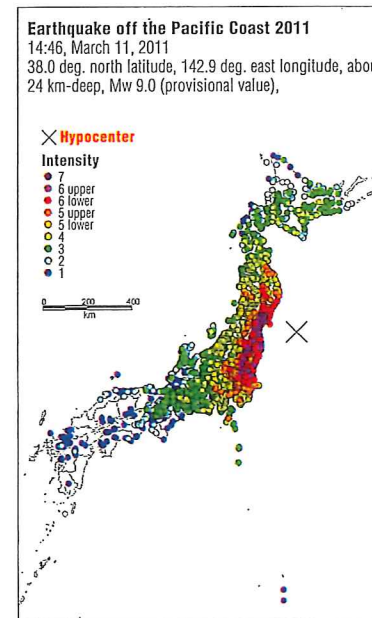


Fig. 1 Seismic intensity distribution in Japan (Source: "Information on the Earthquake off the Pacific Coast 2011" by the Headquarters for Earthquake Research Promotion)

The earthquake induced huge tsunami, causing tremendous damage. The dead and missing persons totaled about 20,000, the injured about 6,000, and about 900,000 houses were destroyed. In addition, much damage occurred in road, railway, coastal and harbor structures and power generation facilities.

## 2 Damage to tunnels

A case survey by the author et al. showed that, as a general rule, tunnels are more prone to seismic damage when 1) the seismic scale is large, 2) the distance from the hypocenter is small, 3) geological conditions are adverse, and 4) there are some defects in the tunnel structure (for example, insufficient lining thickness, cavity on the back of the lining). For instance, with an earthquake of around Mw 8, damage occurred in the range of approximately 30 km from the hypocenter.

The 3.11 earthquake of Mw 9.0 was the largest in recorded history. However, since the tunnels in the affected region were rather distant from the hypocenter, 130 km or more, damage to the tunnels was relatively small. Almost all road tunnels remained undamaged, whereas the railway tunnels suffered minor damage. There were only four railway tunnels that needed restoration on the Shinkansen lines and thirteen on conventional lines. Almost all the damage was insignificant detachment and spalling of the arch lining. The necessary restoration was therefore minor work such as hammering off the detached lining concrete.

## 3 Damage to the Fukushima Tunnel

The Fukushima Tunnel on the Tohoku Shinkansen line was the most seriously damaged. It is a double-track tunnel about 150 km from the, hypocenter 11,705 m long. The geology of the site is mainly composed of folded tuff and mudstone. The typical damage was deterioration of the central passage and track deformation caused by heaving of the sub-grade. The lining concrete did not collapse, nor was there any cracking, detachment, or spalling in the arch or the side walls.

An opening up to 120 mm was produced between the central passage and sub-grade concrete (Photo 1). Fig. 2 shows the level survey results for the northbound track. Such deterioration was deemed to be caused by the weak and complex geology and by the insufficient thickness and curvature of the invert concrete.

There was no report of damage to the tunnel structures due to the tsunami responsible for enormous loss of lives.



Photo 1 Opening between sub-grade concrete and central passage1)

**Note:** "Intensity" of earthquake used in this article is the scale of the Japan Metrological Agency. It is the scale used in Japan for representing the degree of seismic shaking.

### Acknowledgement:

The seismic damage to tunnels discussed in this article is based on the information collected by the Tunnel Engineering Committee of the Japan Society of Civil Engineers, and information of damage to railway tunnels was provided by East Japan Railway Company. The author sincerely thanks them for their valuable support.

### Reference:

1) East Japan Railway Company: SED (Structural Engineering Data) No.37, in Japanese, 2011.11

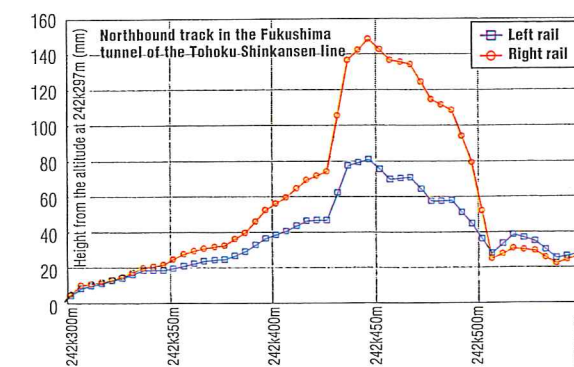
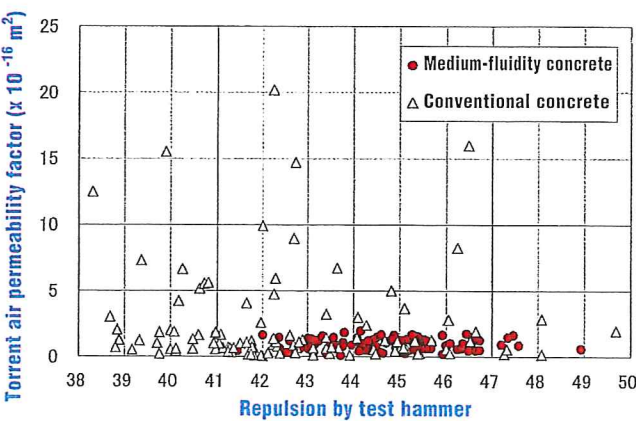
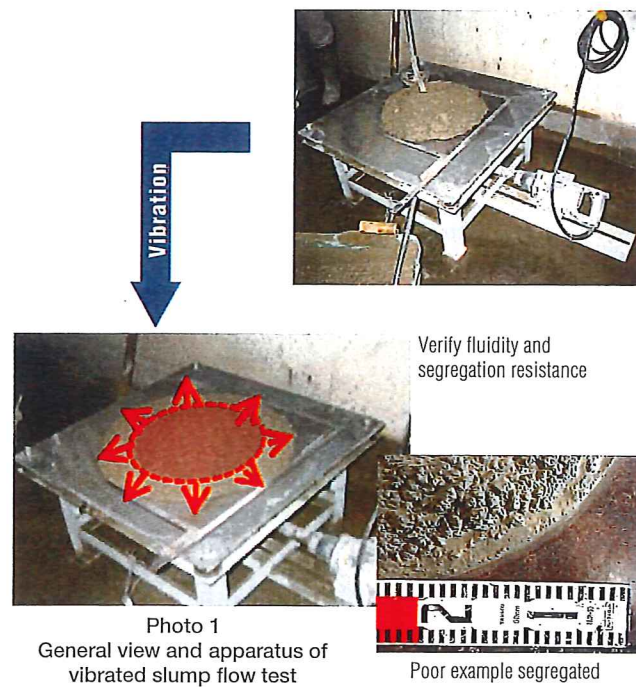


Fig. 2 Results of level survey of the northbound track1)

## Research and Development of Medium-fluidity Concrete

A problem anticipated with lining concrete is decrease of density due to insufficient compaction at joints of the crown portions. Medium-fluidity lining concrete has been developed with consideration given to the simple structure of lining and cost efficiency. It is prepared by adding admixtures such as lime stone powder and fly ash, to make slump flow 35 to 50 cm, that is, between conventional concrete (slump of 15 to 18 cm) and high-fluidity concrete (slump flow around 65 cm). The vibration frequency that optimizes the initial fluidity and segregation resistance was verified by vibrated slump tests (Photo 1). By reproducing the optimal vibration frequency in a form with a form vibrator, high quality concrete can be produced regardless of operator's skill (Fig. 1), and work efficiency is improved.



Note: Air permeability is a measure of density; the smaller is the permeability, the higher is the density.  
 Fig. 1 An example of quality improvement with lining concrete

## On-site Visualization for Tunnel Engineering

On-Site Visualization (OSV) of measurement results is a concept for displaying safety/risk information on site in real time, without "complicated and costly judgment processes." The Light Emitting Deformation Sensor (LEDS) is new technology for field measurement and safety management, which allows workers to visually figure out the on-site situation. The LEDS emits different color light depending upon the magnitude of deformation (Photo 1) enabling early detection of an abnormality, thereby preventing an accident. OSV sensors other than the LEDS developed thus far include Light Emitting Converter (LEC) and Light Emitting Inclinometer Sensor (LEIS). The LEDS was used in a tunneling project in weak geology with a large overburden, for safety management at the face and deformed sections (Photos 2 and 3). The LEDS made it possible for tunneling workers to confirm the actual status of deformation. Consequently, the safety of workplace was improved.

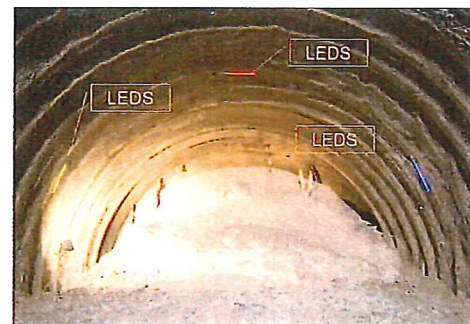
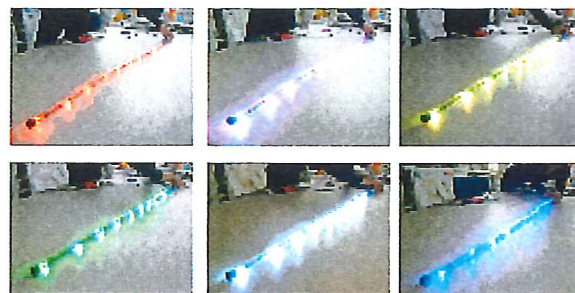


Photo 1 Aspects of light emission  
 Photo 2 LEDSs at the face  
 Photo 3 LEDSs at a deformed section

## A Multi-path Radar Inspection Car for Lining Concrete Diagnostic System

A concrete lining inspection car (CLIC) equipped with an electromagnetic wave multi-path radar has been developed. This is a new technique for diagnosing the lining of tunnels on the Shinkansen lines, which supersedes the conventional hammering test. The CLIC, a self-propelling motor car on the Shinkansen track, performs non-destructive inspection of the internal state of the tunnel lining. Data obtained by the CLIC is combined with image data of the tunnel lining surface taken by the tunnel lining scanning car (TuLIS), to be displayed as an electronically developed image of the lining surface and internal state. Data of deterioration on the electronically developed image is registered in the maintenance assistant system for railway structures (MARS), for comprehensive management.



(Contact:tk-saito@jreast.co.jp)  
 Photo 1 Concrete Lining Inspection Car (CLIC)

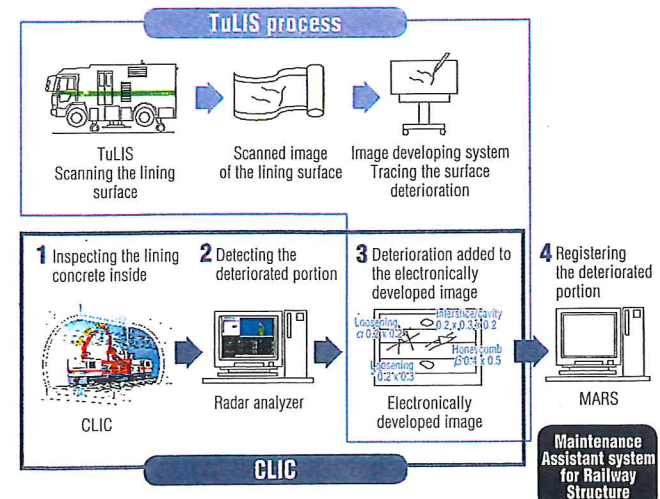


Fig. 2 Combination of CLIC and TuLIS

## A New Non-open Cut Construction Method for Underpasses (Ground cutting JES method)

The ground cutting JES (Jointed Element Structure) method places elements underground, while cutting ground and obstacles by means of a cutting wire. This method reduces overbreak and interstices produced during advance between the top of the cutter edge unit and ground, and restrains heave and settlement of tracks. While the cutting wire in front of the top of the cutter edge unit is cutting earth, boulders and other obstacles, steel elements are inserted into the ground. Adjacent elements are assembled with special joints (JES Joints) that transmit forces. The elements thus placed are filled with concrete, to form a permanent structure.

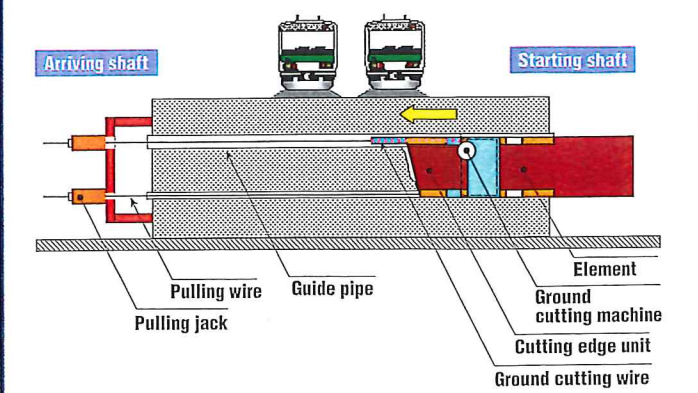
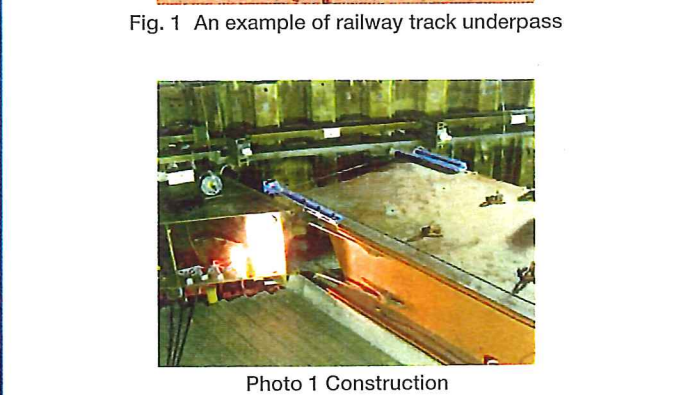
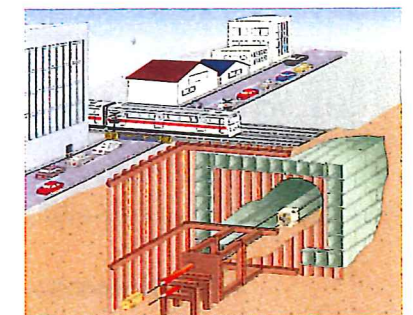


Fig. 2 Overview of the ground cutting JES method

