CONSTRUCTION PROJECT OF UNDERSEA NATURAL GAS TRANSMISSION PIPELINES ACROSS ISE BAY

(HIGH-SPEED CONSTRUCTION OF LONG-DISTANCE UNDERSEA TUNNELS AND PIPELINES)

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1. Background & Aims

The construction of undersea tunnel across Ise Bay was proposed to improve flexibility and stability of natural gas supply by using pipe lines connecting between LNG Terminals located on the east coast and the west coast of Ise Bay. This project has been jointly operated by Chubu Electric Power Co., Inc. (CE) and Toho Gas Co., Ltd. (THG). The construction started in 2008 and is scheduled to be completed in 2013. Figure 1 shows the schematic diagram of

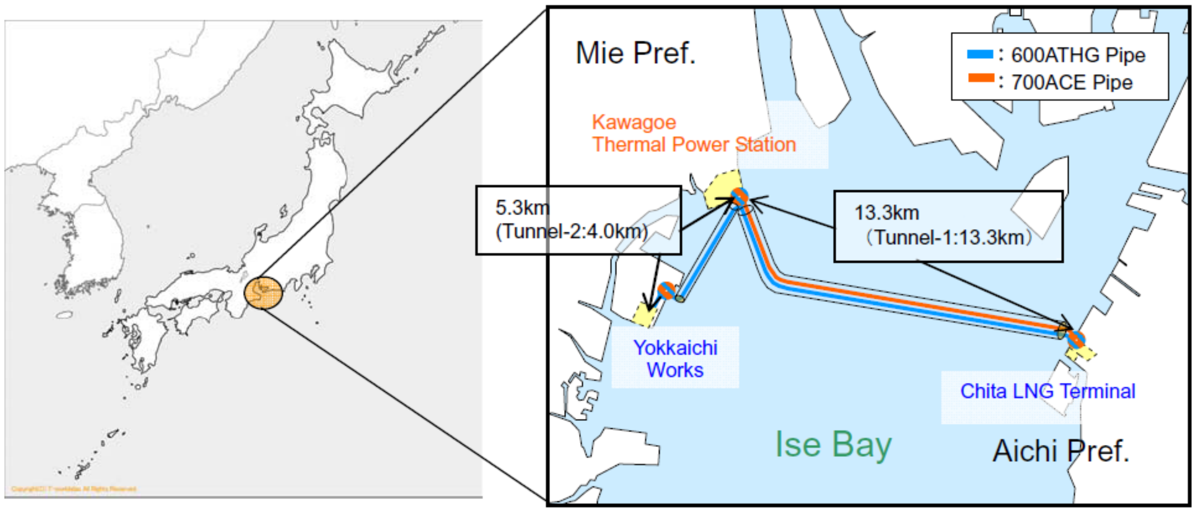


Figure 1 Schematic diagram of the route of Cross Ise Bay Gas Transmission Pipeline and existing LNG Terminal/ Thermal Power Station

Table 1 Specification of pipeline

	Design pressure	Nominal diameter	Length
CE	7MPa	700 ㎜	13.3km
THG	7MPa	600 ㎜	18.6km

this project. A red line indicates a pipe line connecting between Chita LNG Terminal to Kawagoe Thermal Power Station operated by CE, and a blue line indicates a pipe line between Chita LNG Terminal to Yokkaichi Works operated by THG. Table 1 shows the specification of pipeline of CE and THG.

This paper reports construction techniques of long-distance and high-speed undersea shield tunnel, direct docking method of undersea tunnel boring machines and efficient pipeline installation techniques in tunnels.

2. Construction of long-distance undersea shield tunnel

2.1 Outline of shield tunnel

As shown in Figure 1, two shield tunnels, Chita to Kawagoe (Tunnel-1: Length; 13.3 km, Diameter; 3.0m) and Kawagoe to Yokkaichi (Tunnel-2: Length; 4.0km, Diameter; 2.0m), have been constructed. Almost entire line of both tunnels has been constructed under high water pressure of over 0.4MPa.

Figure 2 shows the cross section view of the pipeline. As shown in Figure 2, In the case of Tunnel-1, two pipes were placed vertically in the tunnel.

Figure 3 shows the vertical section view of the pipeline. As shown in Figure 3, the depth of the tunnels is about 45m, and the thickness of the cover is about 37m. In the case of the construction of the Tunnel-1, two tunnel boring machines started from both sides of the tunnel, Chita Shaft and also Kawagoe Shaft, in order to achieve long-distance and high-speed construction of undersea tunnels. Then, direct docking method of undersea tunnel boring machines was accomplished at the middle of the Tunnel-1. This underground docking technology enabled to construct 13.3km undersea tunnel quite rapidly.

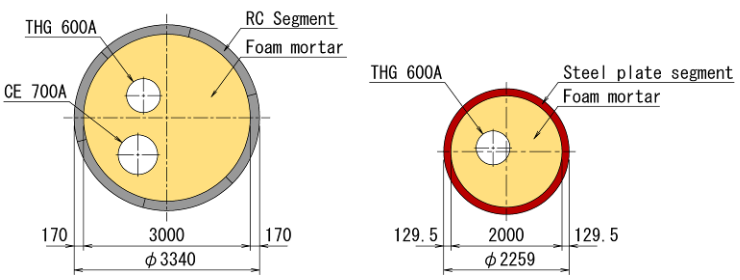
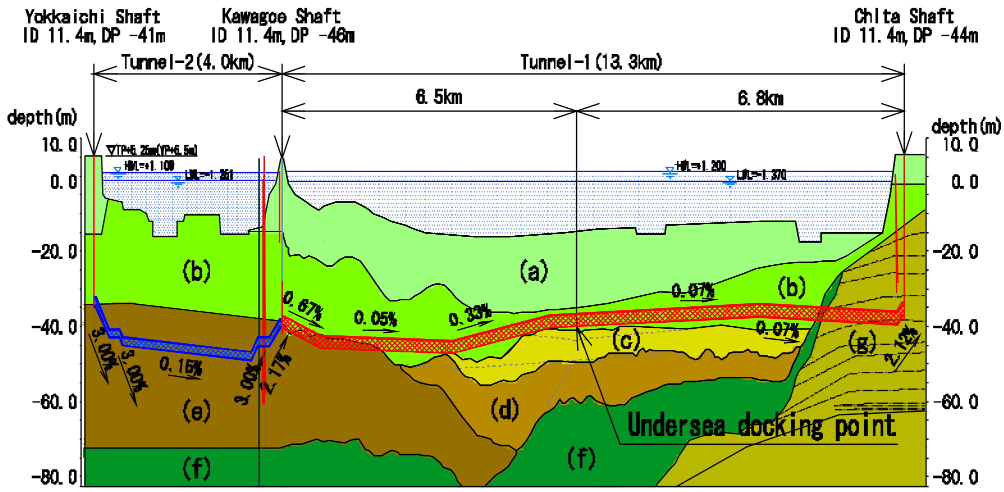


Figure 2 Cross section view of the pipeline



(a) NANYOU Layer N=0-18 clay soil / sandy Soil
(b) NANYOU Layer N=0-4 clay soil
(c) NOUBI Layer N=0-23 clay soil / sandy Soil /gravel
(d) DAIICHI REKI Layer N=20-50 gravel
(e) upper part of ATSUTA Layer N=10-30 sandy soil / gravel
(f) lower part of ATSUTA Layer N=6-50 clay soil
(g) TOKAI Layer group N=50 hardpan

Figure 3 Vertical section view of the pipeline
(Red line: Tunnel-1 route, Blue line: Tunnel-2 route)

2.2 Outline of Design

2.2.1 Geological Condition

Geological profile of Ise Bay was analyzed based on the boring data [1) 2)], the past geological and geotechnical investigation and the sonic survey conducted along the route of the tunnel for this project. Vertical section, extrapolated from those data, is shown in Figure 3.

To avoid excavation of gravel as little as possible and to meet conditions stated in the following section, the tunnel alignment has been planned in upper part of ATSUTA layer (Sandy Soil / Gravel, N-value = 10 - 30) and NANYOU clay layer (N-value = 0 - 4) on Kawagoe side, and in TOKAI Layer group and NANYOU clay layer on Chita side.

2.2.2 Basic Concept of Design

As the equipment in the tunnels should be maintenance-free, it was decided to fill up the tunnel with fill material after gas pipes were installed. The segment was designed as a permanent structure and considering seismic condition. In setting the alignment, following conditions were considered so that workability and long-term structure stability would be ensured, and the tunnel wouldn't affect the environment of the coast.

Distan ce from proximity structures shall be more than 1.5 times longer than the diameter of the tunnel

Maximum gradient is 5 %

Minimum earth covering is 5 meters on land and 10 meters in undersea area

Consideration of future construction plan of new sh ipping routes and anchorage in harbor area

Safety against buoyancy during earthquake

Connection with vertical shaft is to be deepen so as not to be affected by consolidation settlement

2.2.3 Segment of Tunnel-1

Figure 4 shows the schematic illustration of the segment. RC segment, the most widely-used type of segment for middle size around 3 meters in diameter, was adopted in consideration of economic efficiency, workability, quality and durability.

Segmental ring is equally divided into 6 pieces (width; 1,350 mm, thickness; 170 mm). Pin joint (DS Joint: Locked Disk Spring Joint) was adopted as a ring joint. Table 2 shows the properties of segment.

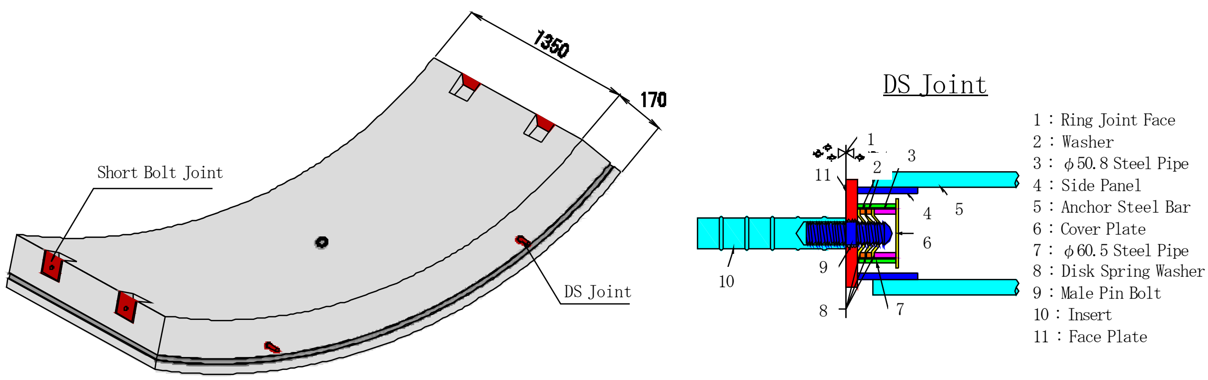


Figure 4 Schematic Illustration of Segment

Table 2 Properties of Segment

Type	DS Segment
Material	Reinforced Concrete
Inner / Outer Diameter	3,000 mm / 4,000 mm
Division	6 Equal Division
K Segment	Inserted in longitudinal direction
Width / Thickness of Segment	1,350 mm / 170 mm
Segment / Ring Joint	Short Bolt Joint / DS Joint
Cement	Portland Blast-Furnace Slag Cement
Compressive Strength of Concrete	54 N/mm2

2.3 Construction Planning

Slurry shield machine was selected in order to deal with long distance construction, underground docking, high water pressure of 0.4 MPa, and rapid construction. Structure of the machine is shown in Figure 5 and Picture 1.

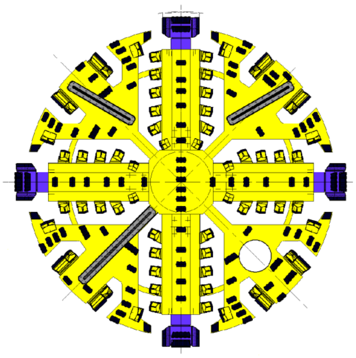


Figure 5 Structural Drawing of Machine for Kawagoe   Picture 1 Shield Machine for Kawagoe

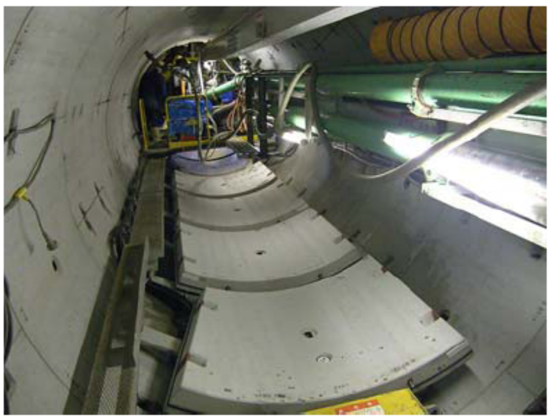
a) Measure against Long Distance Construction (Ensuring of Durability)

In order to deal with long distance construction, the machine was equipped with a total of 3 row bits: double row precut bits and single row tool bits. Ultra-hard tip was made of E-5, which provides with impact-resistance and friction-resistance.

b) Measure against Rapid Construction

In order to ensure excavation of 650 meters in length per month on Kawagoe side and 600 meters per month on Chita side, Self-propelled 6-tons battery locomotive (Two cars at maximum. Maximum speed is 10 km/hr) ran from the tunnel mouth to the face. Segment setter carriage, shown in Picture 2, was installed. The carriage enabled to discharge 2 rings of segment at one time. In addition, segment feeder with slide table, shown in Picture 3, was equipped. And the sites were operated by day and night shifts.

Picture 2 Segment Setter Carriage



Picture 3 Supply of Segments

c) Underground Docking

Mechanical docking method was selected for underground connection, which enabled each machine to deal with both accepting and inserting whichever machine arrives first.

Figure 6 shows the construction process. Both magnetic and RI survey were carried out to investigate relative position of both machines. Table 3 summarizes the both methods.

Allowable connection tolerance was 50 mm. Ground freezing method was used for waterproof. Therefore freezing pipes were attached to the face of the machine body.

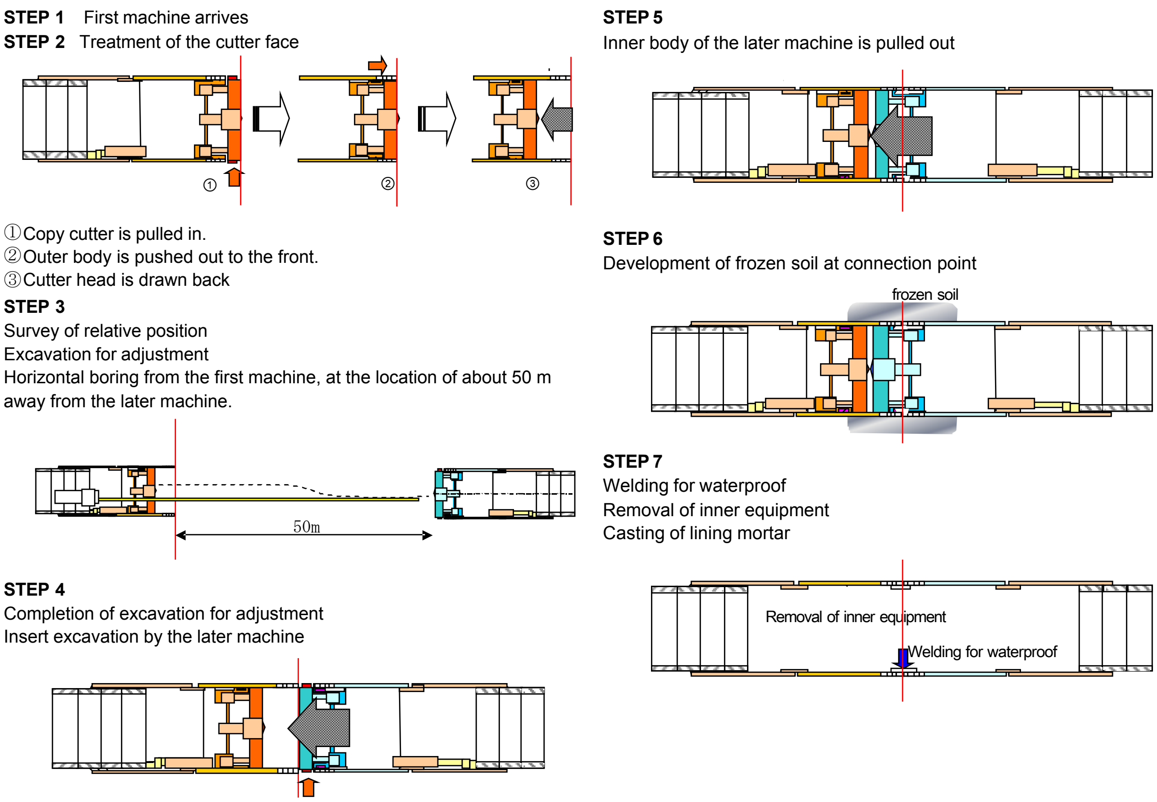


Figure 6 Construction process of Underground Docking

Table 3 Relative Position Survey Method

	Accuracy	Method	Equipment	
			Sending	Receiving
Magnetic Survey	±100 mm	Position of horizontal boring is figured out by magnetic waveform generated by cutter rotation.	Three magnets embedded in cutter face of shield machine	Six magnetic sensor embedded in periphery of horizontal boring machine
RI Survey	±1 mm	Position of horizontal boring (RI sensing rod) is figured out by detecting radiation source.	Radiation source attached to horizontal boring and RI sensing rod	RI sensor attached to man hole at bulk head

2.4 Record of Construction

2.4.1 Record of Excavation

Figure 7 shows the record of excavation. Average progress per month during actual excavation, except preliminary excavation, was 701 meters on Kawagoe side, which is much longer than original plan of 650 m/month. On Chita side, average progress per month was 644 meters, which also exceeded original plan of 600 m/month.

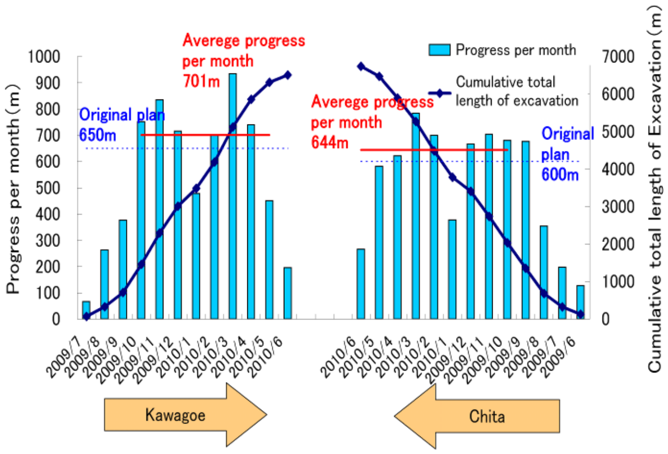


Figure 7 Record of Excavation

Picture 4 Inside of Tunnel

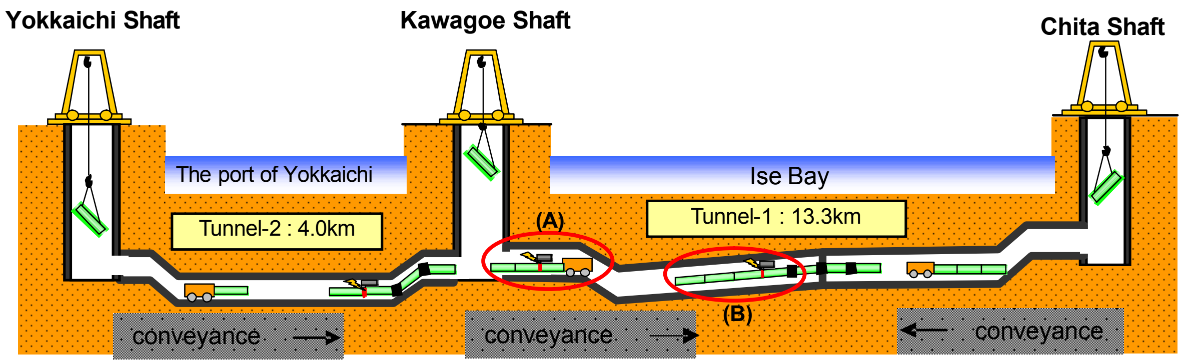
2.4.2 Record of Underground Docking

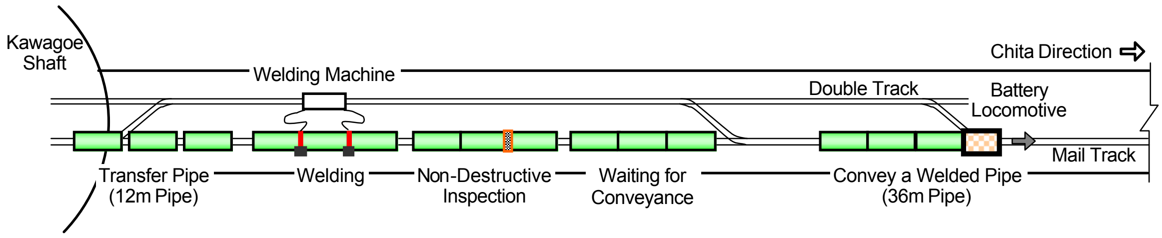
Relative gap was 57 mm in horizontal direction and 33 mm in vertical direction when distance between two machines was 50 meters. It was proved that base line measurement had been accurate.

Relative gap was 9 mm in horizontal direction and 1 mm in vertical direction when two machines were finally docked. Although the underground docking was carried out under high water pressure (0.4 MPa) after more than 6-km excavation, the docking was accomplished safely with ground freezing method. The construction of the Tunnel-1 was completed in October, 2010.

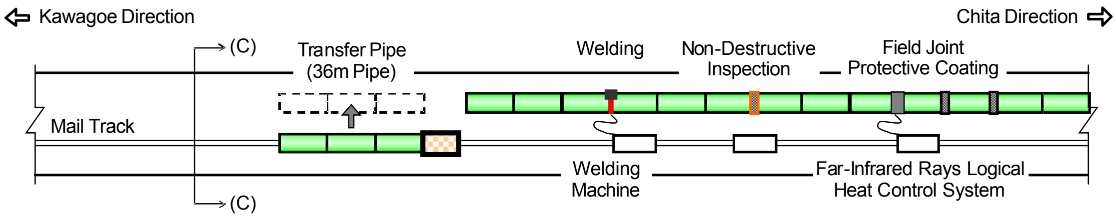
3. Efficient Pipeline Installation Work and Site Management System in the Tunnel

Because the work for pipeline installation in this project needs to be implemented in the long-distance undersea tunnel, efficient pipeline conveyance and installation system are required to reduce construction term and costs. For this reason, in order to improve work efficiency, pipeline installation was started at the middle point of the Tunnel-1 and extended to both side shafts of the Tunnel-1, i.e. Kawagoe Shaft and Chita Shaft, as shown in Figure 8.

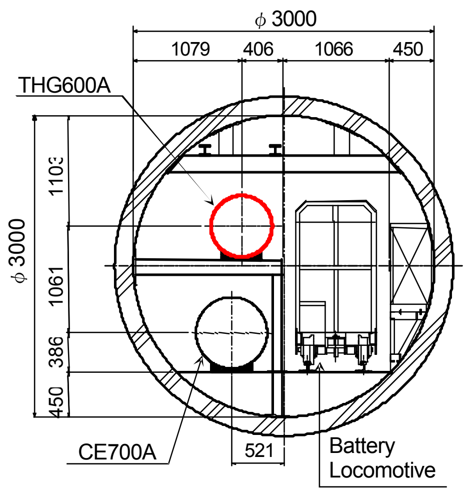




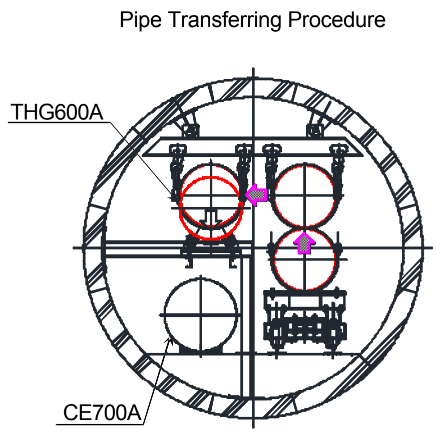
Plan View of Tunnel-1 at Bottom of Kawagoe Shaft （Point (A) in the figure above ）



Plan View of Inside Tunnel-1 （Point (B) in the figure above ）



Standard Cross Section in Tunnel-1



Cross Section (C)

Figure 8 Processes of Gas Pipeline Installations in Tunnels

3.1 Efficient Pipeline Installation Work in the Tunnel

Figure 9 shows the workflow of pipeline installation in the tunnel by which work efficiency and safety were secured. The photographs showing each work unit are illustrated in Picture 5.

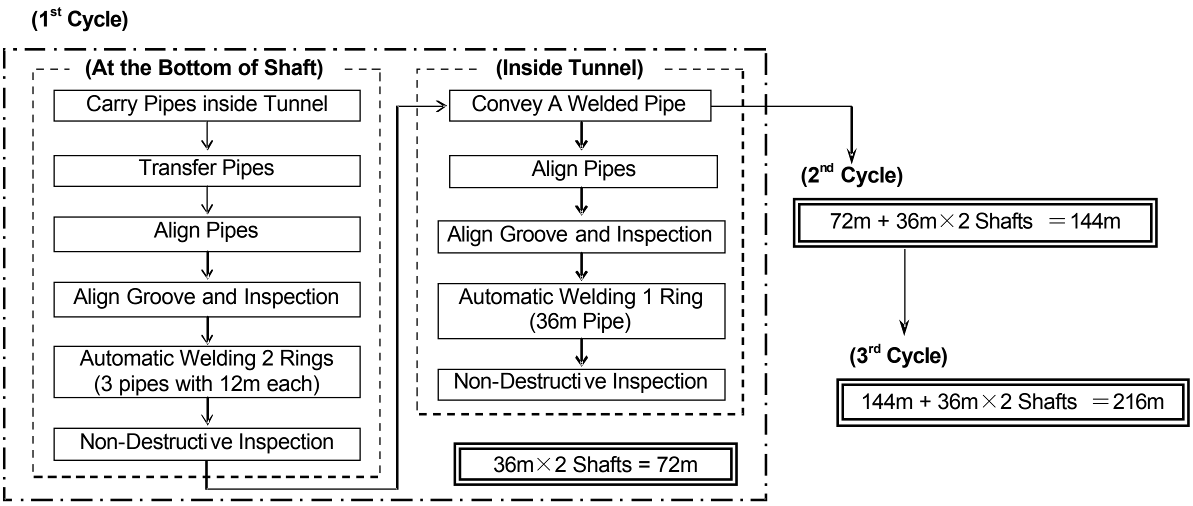
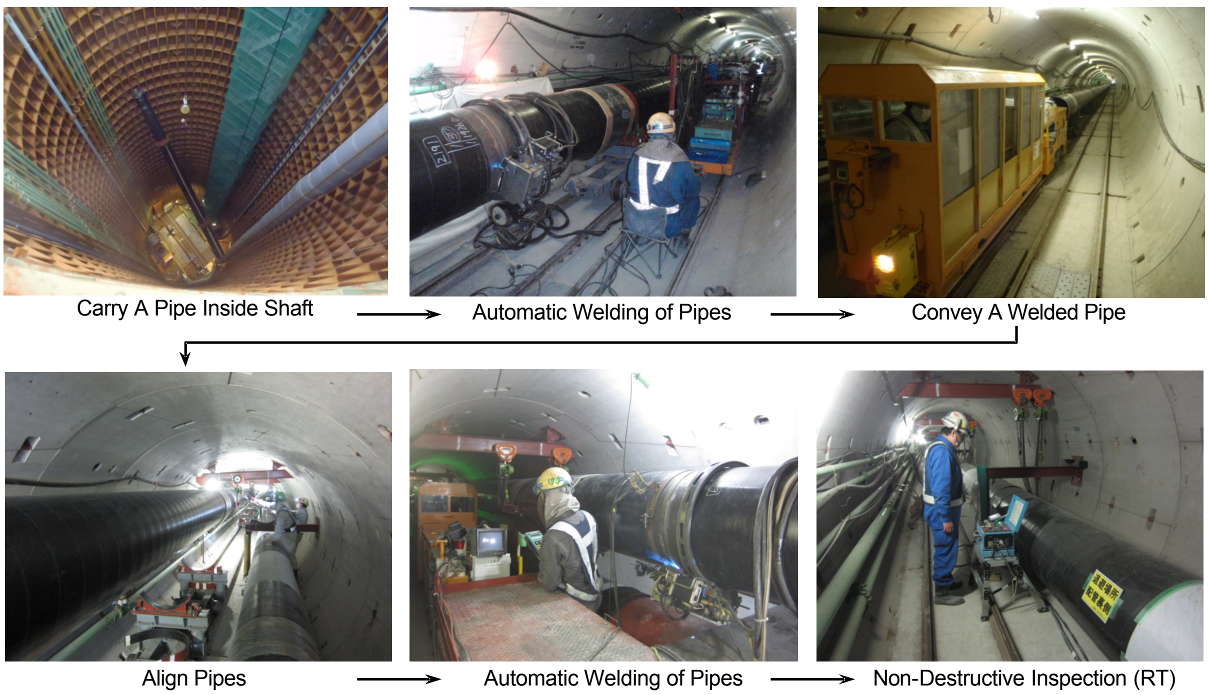


Figure 9 Workflow of Pipeline Installation inside Tunnel and Throughput

At the bottom of the shafts, three pipes with 12 meters long each were welded together to be one piece of 36 meters long. Then, the welded 36 meters long pipe was carried to the end of the pipeline already installed and welded together. Through one cycle of this workflow, the pipeline was extended by 36 meters long at once.

As this work procedure had been usually repeated two or three cycles per day at both side shafts, it was made possible to extend pipeline by 144 or 216 meters long per day.



Picture 5 Site Photographs of Pipeline Installation Work inside Tunnel

3.2 Site Management System in the Tunnel

In order to holistically manage pipeline installation work in the tunnel, the Site Management System was developed exclusively for pipeline installation work in the tunnel. The characteristics and configuration of the system are shown in Table 4 and Figure 10 respectively.

This system made it possible for supervisors at aboveground (1) to communicate with workers in the tunnel, (2) to confirm working environment in the tunnel through visual monitor, (3) to confirm location of workers and battery locomotives and (4) to confirm results of welding and non-destructive inspection. Consequently, these real-time monitoring functions of the system contributed greatly to the safety and efficiency of the pipe installation work in the tunnel.

Table 4 Characteristics of the Site Management System

Item	Description
Communication	Communication between supervisors at aboveground and workers inside tunnel who possess explosion-proof IP phones. This plays an important role from safety point of view in emergency situations as a communication measure.
Entrance and Exit Control	Personal identification and location detection of workers inside tunnel through automatic location data acquisition of IP phones.
Working Environment Control	Real-time monitoring through web camera equipped to control and maintain suitable working environment inside tunnel. The real time monitoring is aimed at continuously measuring environmental data inside tunnel such as CH_4, O_2 and CO_2 and at issuing a warning to workers in abnormal circumstances.

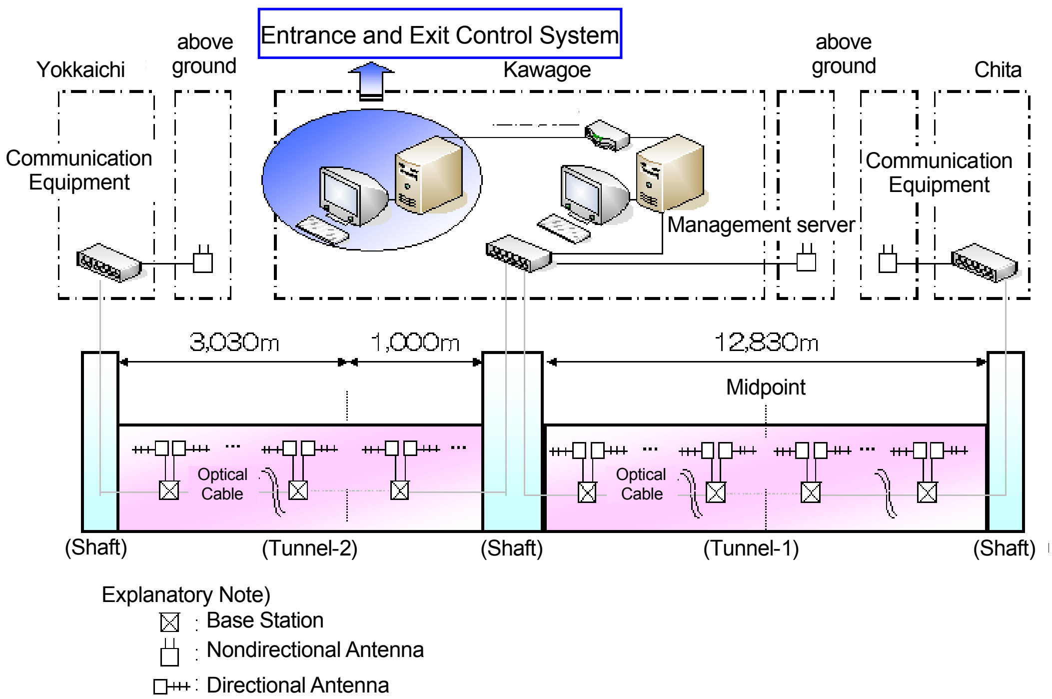


Figure 10-1 System Configuration of the Site Management System

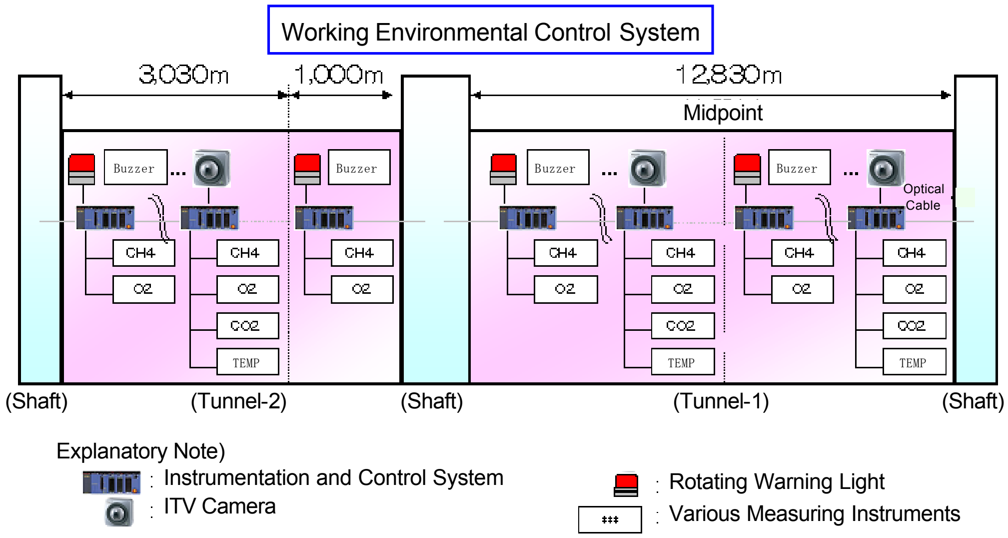


Figure 10-2 System Configuration of the Site Management System

4. Improvement of Quality and Safety of Field Joint Protective Coating works in Tunnel

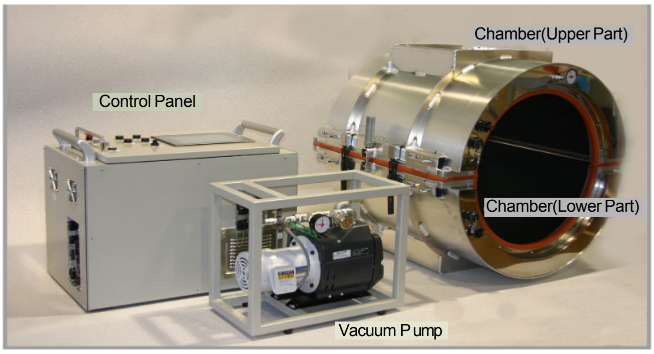
It is realistically impractical to excavate and repair the pipeline after the pipeline is installed inside the tunnel in the deep ground.

For this reason, in order to minimize the risk of external corrosion, the far-infrared rays logical heat control system was developed and applied in this project. Appearance and device configuration of the system are illustrated in Picture 6 and Table 5 respectively. The features of the system are as follows ;

- The weight and dimensions of the system are designed to enable workers to work even in the narrow space of the tunnel-2.
- A good quality is stably secured for field joint protective coating by automatically controlling for degree of vacuum, heating temperature and heating time.
- No harmful void exists in adhesive layer due to the thermal contraction of heat-shrink sleeve under depressurized conditions.
- Neither uneven heating nor overheating exists due to uniform heating of far-infrared heating system.
- No skilled techniques are necessary as the working procedures since the system is fully established and automated.

After covering field joints and heat-shrink sleeve within the vacuum chamber, pressure inside the chamber is reduced to eliminate dust and condensation of water vapor. Then, the heat-shrink sleeve is heated by far-infrared rays in the vacuum chamber and is consequently shrunk. Picture 7 shows the site photographs of the far-infrared rays logical heat control system.

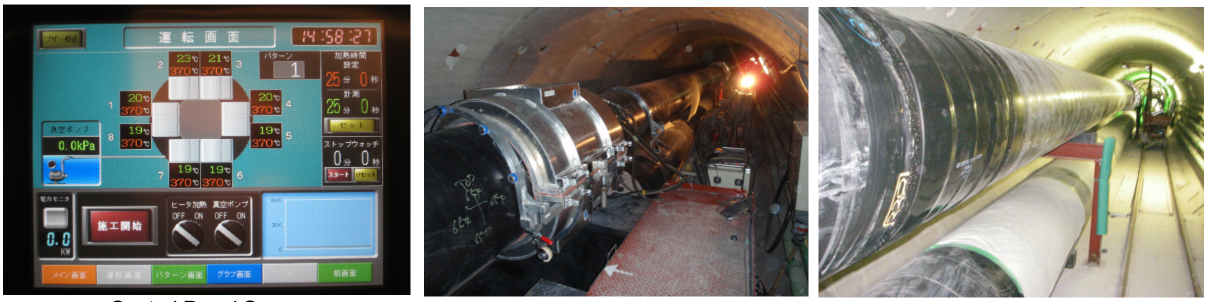
With the introduction of the far-infrared rays logical heat control system, no use of fire is required for heating field joint protective coating, thus contributing to the safety of workers in narrow working space inside the tunnels.



Picture 6 Appearances of the Far-Infrared Rays Logical Heat Control System

Table 5 Device Configuration of the Far-Infrared Rays Logical Heat Control System

Item	Dimension	Weight
Chamber	φ980×L840 ㎜	40kg×2
Control Panel	W450×L750×H550 ㎜	50kg
Vacuum Pump	W300×L500×H450 ㎜	30kg
Cables	Power Cable 2 ㎜ ^{2}×8 cores×20m×2units	—



Control Panel Screen　　Setting of Vacuum Chamber　　Appearance of Heat-Shrink Sleeve After Construction

Picture 7 Site Photographs of the Far-Infrared Rays Logical Heat Control System

5. Conclusions

Almost entire line of undersea tunnels has been constructed under high water pressure of over 0.4MPa. However, long-distance and high-speed construction of undersea tunnels have been achieved by utilizing of the direct undersea tunnel boring machines docking techniques, efficient gas pipeline installation techniques in tunnels and total management system of pipe installation in tunnels. The construction progress speed of the Tunnel-1 and the Tunnel-2 are 216 meters long per day and 48 meters long per day respectively. The application of Far infrared rays Logical Heat Control System makes it possible to realize quality and safe construction of pipeline in narrow space. It is sure that these techniques will promote the construction of pipeline, and these are expected to contribute the expansion of efficient and reliable gas transmission network in the world.

References

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2) Aichi and Mie Prefecture, Planning Bureau, Ministry of Construction Result of Investigation of the Grounds in the Northern Coastal Region of the Bay of Ise, Vol.1, Aug., 1962.