Upgrading Dam under Operation

YAMAUCHI Kazunori : Manager, Gate & Penstock Design Department, Steel Structure Engineering Division, IHI Infrastructure Systems Co., Ltd.
FUKUSHIMA Noriaki : Manager, Gate & Penstock Design Department, Steel Structure Engineering Division, IHI Infrastructure Systems Co., Ltd.
TAMURA Hiromichi : Manager, Gate & Penstock Design Department, Steel Structure Engineering Division, IHI Infrastructure Systems Co., Ltd.

In recent infrastructure development, it is required to further utilize existing stocks, and many projects of the upgrading dam are implemented and planned in the water control and water utilization. IHI Infrastructure Systems Co., Ltd. has also participated in several upgrading dam projects and introduces previous experiences from the standpoint peculiar to upgrading dams in order to make reference to similar projects in the future.

1. Introduction

Japan is currently facing the need to make effective use of existing stocks while reducing total cost for infrastructure development, and endeavors to respond to this need is being made nationwide. From this perspective, it is thought that efforts to utilize existing dams for a prolonged period of time in an effective and sustained manner are important for addressing challenges in water control and utilization; and various approaches, including flexible management, upgrading dam heights, and construction of tunnel spillways, are being planned and implemented for many existing dams.

IHI Group has often contributed to the implementation of such approaches as it has expertise in the design, fabrication, and installation of steel structures, which is key to these approaches.

IHI has long been making reports[(1), (2)] on renovations of existing facilities. Focusing on "upgrading existing dams," which has a broader scope than renovations of a single facility, this article describes technical measures for various subjects in the execution of works on an in-service dam, in order for the measures to serve as a reference for entities participating in future projects.

2. Kanogawa Dam Riparian Release Conduit Installation Project

Project title	FY2012−2013 Kanogawa Dam Riparian Release Conduit Installation Project[(3)]
Owner	Shikoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Term of project	From October 2012 to October 2014

2.1 The course of events during the redevelopment project and challenges in the execution of works

The Kanogawa Dam is a multipurpose dam with an effective reservoir capacity of 29.80 million m^3. It was constructed on the Hijikawa River — in the area beyond Hijikawacho Yamatosaka, Ozu City, Ehime Prefecture — for the purposes of flood control and water utilization (power generation) in 1959.

The riparian release conduit installed in this project was designed to eliminate cold water release and prevent the prolongation of turbid water release, as well as to suppress the eutrophication of reservoirs.

This conduit is connected to selective water withdrawal equipment that was separately installed (beyond the scope of this project) on an intake conduit, enabling water to be released at a rate of up to 10 m^3/s at the lowest water level after dam improvement.

Since the project was executed while the dam was in service, difficult work that involved underwater operations at a depth of about 30 m was performed upstream in the lake created by the dam.

The chamber, one of the unique aspects of this project, had two major roles: ① during the digging of the tunnel through which the intake conduit was installed, it served as a temporary cofferdam when the tunnel was cleared; and ② it constituted part of the intake conduit channel through which water was conducted from the selective water withdrawal equipment to the main control gate after the completion of the selective water withdrawal equipment.

Since the chamber was a complicated welded structure subjected to a high water pressure and needed to be divided into six blocks due to transportation-related constraints, it was challenging to accomplish the on-site assembly of the chamber with high dimensional accuracy. In addition to ensuring high accuracy for the chamber itself, we had another challenge; we had to work underwater to achieve high installation accuracy on site. **Figure 1** shows the outline of the chamber and block arrangement for transportation.

2.2 Brief specifications of key facilities

The following are the brief specifications of each facility.

(1) Main control gate

Type	Jet flow gate
Effective diameter	ϕ1.200 m

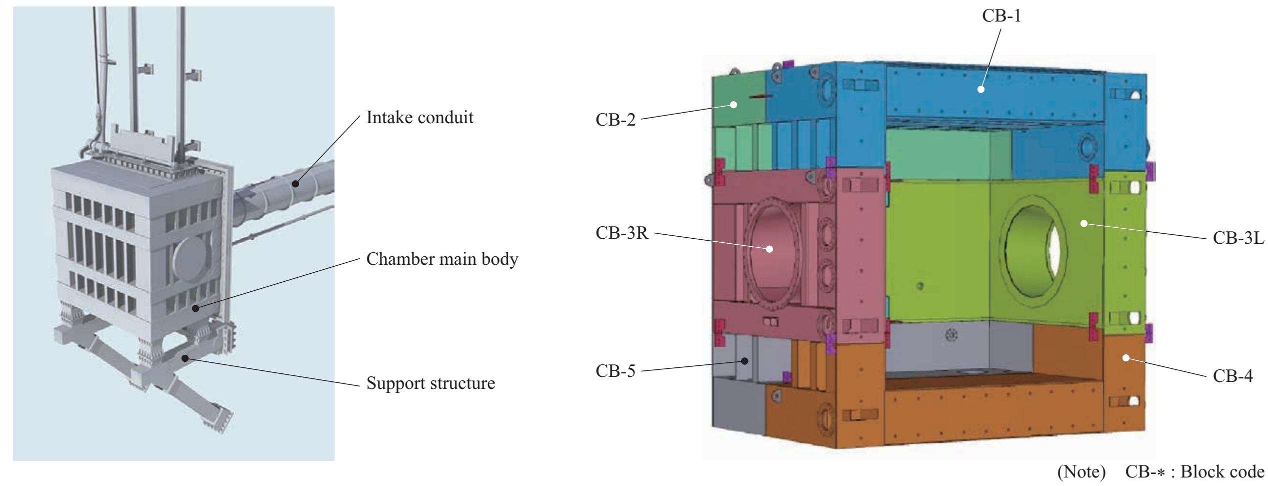

Fig. 1 Outline of the chamber and block arrangement for transportation

(2) Intake conduit

Structure	Steel stiffener system
Bell-mouth tube diameter	ϕ1.950 – 1.500 m
Intake conduit diameter	ϕ1.500 m
Reducing tube diameter	ϕ1.500 – 1.440 m
Outlet tube diameter	ϕ1.700 m

(3) Guard gate

Type	Plate structure steel roller gate
Clear span	1.950 m
Effective height	1.950 m

(4) Chamber

Type	Steel box girder structure — inside skin plate type —
Inner space width	4.000 m
Inner space height	4.000 m
Inner space depth	3.200 m

2.3 Key points for addressing challenges

In order to ensure the dimensional accuracy of the chamber itself, it was important to avoid misalignment between blocks. We therefore devoted much energy to ensuring accuracy; for example, we first temporarily assembled all blocks and performed positioning of the surfaces to be machined, and then disassembled the blocks and machined the joining surface of each block.

In addition, we took several steps to ensure underwater installation accuracy; for example, we used high-accuracy templates in the installation of the chamber, which had been preassembled to the guard gate guide frame. Thus, we were able to successfully ensure high installation accuracy within the limited time allowed for the execution of the work. **Figure 2** shows the installation procedure using the original steel templates.

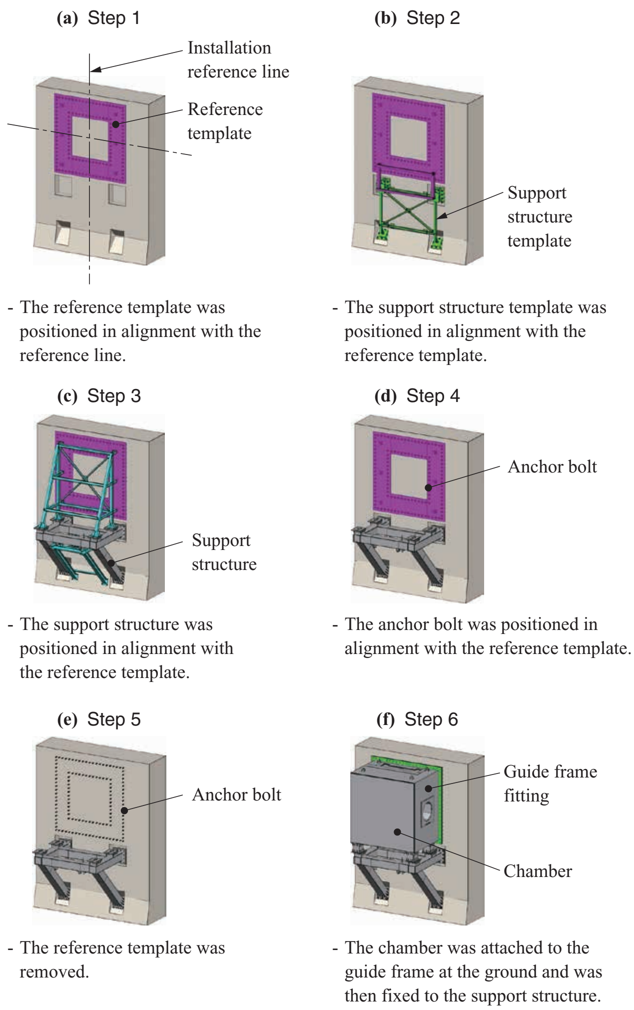

Fig. 2 Installation procedure using the original steel templates

3. Additional outlet facilities of the Tsuruda Dam

3.1 The course of events during the redevelopment project and challenges in the execution of works

The Tsuruda Dam (Kagoshima Prefecture), situated in the middle of the Sendai River, is a multipurpose dam with an effective reservoir capacity of 77.50 million m^3. It was constructed for the purposes of flood control and water utilization (power generation) and was completed in 1966. **Figure 3** provides a panoramic view of the Tsuruda Dam.

Fig. 3 Panoramic view of Tsuruda Dam

In July 2006, there was the great damage in watershed area of the Tsuruda Dam by the catastrophic flood caused by the record torrential rains centered on the northern part of Kagoshima Prefecture, and the Tsuruda Dam Redevelopment Project was planned. Specifically, it was planned to increase the maximum flood control capacity from 75.00 million m^3 to 98.00 million m^3 in order to reduce the damage caused by a flood. This plan included the installation of additional outlet facilities, which involved the construction of five tunnels through the dam, and for this purpose, drilling was performed while the dam was in service. From this perspective, this project was the largest in scale among the dam redevelopment projects in Japan. IHI Infrastructure Systems Co., Ltd. undertook part of this dam redevelopment project.

In this project, we faced several challenges. For example, it was required to reduce the operations performed concurrently with associated works performed in the bored tunnels for installing discharge pipes, as well as to reduce the number of operations that had to be performed in a tunnel in order to avoid having to work in such a small space. Similarly, many of the operations related to the outlet gates had to be performed in small spaces concurrently with associated works and on a tight schedule at that, so careful coordination with the associated works and the acceleration of such operations were required. Moreover, there was another challenge related to the outlet gates. With SUS304 used as a material for many components of the outlet gates because of the recent move to improve maintainability, it was a challenge to find a way to validate the soundness of those parts so critical to strength as they are welded on-site.

3.2 Brief specifications of key facilities

3.2.1 Additional discharge pipes

Project title	Tsuruda Dam Additional Discharge Pipe Fabrication and Installation Project(4)
Owner	Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Term of project	From October 2012 to March 2016

Table 1 lists the additional discharge pipe specifications.

3.2.2 Additional outlet gates

Project title	Tsuruda Dam Additional Outlet Gate Fabrication and Installation Project(4)
Owner	Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Term of project	From February 2013 to March 2016

Regarding the additional outlet gates, **Table 2** lists the main control gate specifications and **Table 3** lists the guard gate specifications.

3.3 Key points for addressing challenges

3.3.1 Additional discharge pipes

In order to reduce operations performed concurrently with associated works, as well as operations in small spaces, we formulated a discharge pipe installation plan. First, with consideration given to the constraints involved in the transportation from the factory to the installation site, the discharge pipes fabricated at the factory were delivered to the installation site in the form of half segment pipes with a length of 3 m. Then, in the assembly yard provided outside the dam, the half segment pipes were assembled into a 6-meter-long pipe (cylindrical pipe). The longer pipes were then transported to the installation site. Since the transportation route included a section of a general road, the section was completely closed and other necessary measures were taken. **Figure 4** provides a photograph of the transportation of the additional discharge pipe.

Moreover, in order to reduce operations in small spaces in the bored tunnels, two longer pipes were coupled with each other on a temporary steel stage and then pulled into the dam by using heavy load moving rollers and an electric winch. **Figure 5** provides a photograph of the coupling of the additional discharge pipes on the temporary steel stage. We did our best to improve the overall work efficiency of this series of processes ranging from transportation to the

Table 1 Additional discharge pipe specifications

Item	Unit	Specifications	
		No. 1 and 2	No. 3
Type	—	Circular cross section, concrete buried steel pipe	
Quantity	—	2	1
Bore diameter	m	ϕ 4.8	
Transition section	m	4.80 (H) × 3.40 (W)	3.80 (H) × 2.80 (W)
Inlet center elevation	m	EL. 95.0	EL. 107.5
Outlet center elevation	m	EL. 82.0	EL. 87.0

(Note) H : Height
W : Width
EL. : Elevation

Table 2 Main control gate specifications

Item	Unit	Specifications	
		No. 1 and 2	No. 3
Type	—	High-pressure roller gate	
Quantity	—	2	1
Clear span × effective height	m	3.40 × 4.80	2.80 × 3.80
Open/close system	—	Hydraulic cylinder system	
Open/close speed	m/min	0.3	
Seal type	—	Front surface square rubber seal	

Table 3 Guard gate specifications

Item	Unit	Specifications	
		No. 1 and 2	No. 3
Type	—	High-pressure roller gate	
Quantity	—	2	1
Clear span × effective height	m	3.40 × 4.80	2.80 × 3.80
Open/close system	—	Hydraulic cylinder system	
Open/close speed	m/min	0.3	
Seal type	—	Rear surface square metal seal	

Fig. 4 Transportation of the additional discharge pipe

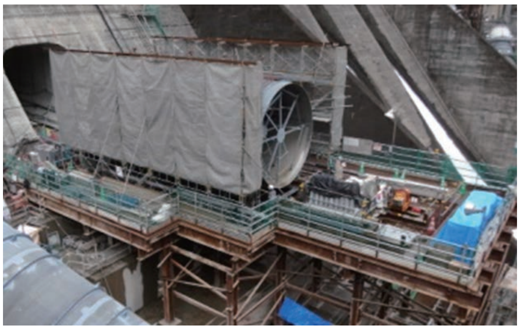

Fig. 5 Coupling of the additional discharge pipes on the temporary steel stage

completion of installation, and accelerated the discharge pipe installation process as described here.

3.3.2 Additional outlet gates

Redevelopment works had to be executed on a tight schedule. In addition, such works had to be executed concurrently by many contractors with little space to work. For this reason, we formulated a plan for the detailed works and managed the processes closely in coordination with the supervisory staff and other contractors.

The additional outlet gates were hoisted for their placement into the dam. For the positioning between each blocks during the placement, we took care to improve workability by using detachable guide fittings, for example, in order to quickly guide the blocks to the correct positions as well as to prevent damage to the flange surfaces.

Furthermore, since the method for the field welding of side girders (SUS304) of the main control gate was full penetration welding with backing metal, it was difficult to validate the internal soundness of the welded metal using conventional methods. We therefore adopted the same method as for inspecting the welds of austenitic stainless steel, which is known as the ultrasonic phased array method. We developed this method in a joint research project with IHI Corporation. This method enabled us to verify the soundness of such welds.

4. Futase Dam Selective Water Withdrawal Equipment Installation Project

Project title	Futase Dam Selective Water Withdrawal Equipment Installation Project[5]
Owner	Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Term of project	From January 2014 to June 2016

4.1 The course of events during the redevelopment project and challenges to the execution of works

The Futase Dam is a multipurpose dam with an effective reservoir capacity of 21.80 million m^3. It was constructed in Chichibu City, Saitama Prefecture, in the upper most reaches of the Arakawa River, a first-class river, for the purposes of flood control, securing a water supply for agricultural use, and prefecture-run hydroelectric power generation (transferred into private hands later). Construction was completed in 1961.

The new selective water withdrawal equipment was installed as additional selective water withdrawal equipment in the water intake part of the hydroelectric power generation unit with a water intake capacity of up to 7.5 m^3/s and output of up to 5 200 kW in order to reduce cold water release and turbid water release to the downstream river. **Figure 6** provides an outline of the whole facility.

Among the types of selective water withdrawal equipment, telescope type semi-cylindrical rubber gate selective water withdrawal equipment was adopted because of its capability to reduce the load acting on the existing dam.

This project had the major challenges as listed below.

(1) The equipment was being added to an existing dam, so it was required to minimize the impact on the dam.

(2) The equipment was located in close proximity to the spillway equipment, so it was required to take the impact of the flow of water on the spillway equipment during release into consideration.

(3) During the installation of structures on the upstream surface of the existing dam, which is a concrete arch dam, it was required to take special measures for quality control.

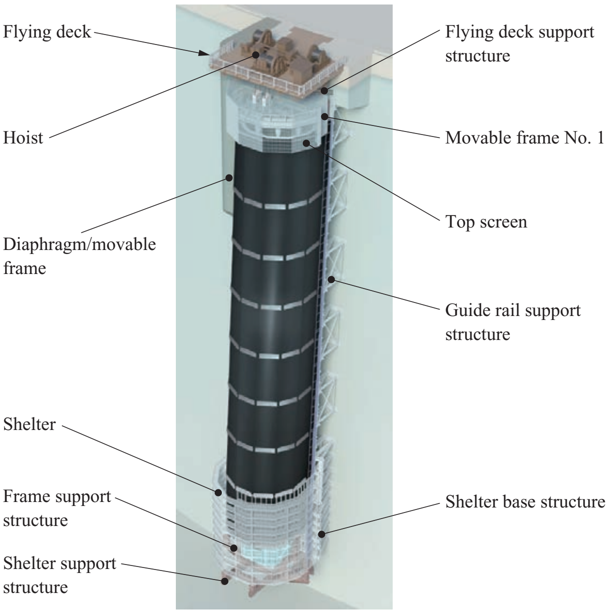

Fig. 6　Outline of the whole facility

4.2　Brief specifications of the water withdrawal equipment

The following are the brief specifications of the equipment.

No. of gates	1 (8 tiers)	
Type	Selective intake works with the telescope type rubber gate	
Dimensions		
Tangential radius of frame		4.000 m
Frame spacing		5.975 m
Maximum quantity of water intake		7.5 m^3/s
Range of vertical movement of frame		
Highest elevation		EL. 539.000 m
Lowest elevation (during water intake)		EL. 498.000 m
Lowest elevation (when fully opened)		EL. 497.700 m

4.3　Key points for addressing challenges

4.3.1　Design of movable frame No. 1

We conducted a study of approaches for reducing the load borne by the hoist and thereby minimizing the impact on the existing dam. Specifically, we planned to reduce the mass of the product and utilize buoyancy. In order to reduce the mass of the product, several measures were taken; for example, lean type duplex stainless steel (SUS821L1) was adopted for the key components and fiber reinforced plastics (FRP) were adopted for the top screen. Meanwhile, buoyancy utilization was achieved by adopting an airtight structure for the piping section. SUS821L1, applied for the movable frame No.1, is about twice as strong as SUS304, and has excellent corrosion resistance. Moreover, in order to determine the dimensions of the members of movable frame No. 1, 3-dimensional frame analysis was conducted because of the complicated structure of this component. **Figure 7** illustrates movable frame No. 1.

4.3.2　Shelter installation

The recently added selective water withdrawal equipment is located in proximity to the existing conduit gate; it is therefore

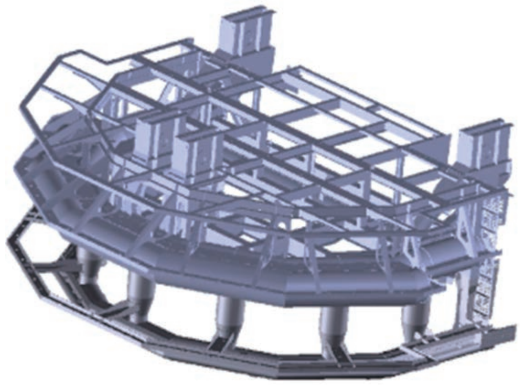

Fig. 7　Movable frame No. 1

subject to the impact of running water released from the conduit gate and entering its inlet. A shelter was installed in order to protect the selective water withdrawal equipment against this running water.

4.3.3　Ensuring of accuracy of installation on the upstream surface of the dam

Measurements of items particularly important to the installation of the selective water withdrawal equipment on the existing dam, such as installation reference lines and dam dimensions, were taken by using pre-installed reference rails with full-scale steel rulers attached to them, and the results were reflected in the mounting dimensions of the respective members. **Figure 8** shows one example of the steel ruler and **Fig. 9** shows the survey using the reference rail.

5.　Kanogawa Dam Tunnel Spillway Outlet Gate Installation Project

Project title	FY2012−2015 Kanogawa Dam Tunnel Spillway Outlet Gate Installation Project(6)
Owner	Shikoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Term of project	From January 2013 to September 2017

5.1　The course of events during the redevelopment project and challenges in the execution of works

An overview of the Kanogawa Dam has been given in **Section 2.1**. The area along the Hijikawa River (Ehime

Fig. 8　Steel ruler

Fig. 9 Survey using the reference rail

Prefecture), where the dam is located, is subject to flood damage due to the geographical characteristics of the river, such as having a low gradient and being narrow, and various flood countermeasures have been implemented in the past. However, it has been impossible to say that the safety factor of floodwaters is adequate, as exemplified by the catastrophic flood that occurred in 1995.

In order to address this issue, the River Development Plan for the Hijikawa River System (Middle-to-Lower Basin Zone) was developed, and the Kanogawa Dam Modification Project was implemented in accordance with this plan. As a part of this modification project, the present project was implemented to install gate equipment and other facilities for release control in the outlet section of the tunnel spillway that was installed to increase the flood control capability of the dam. The new gate equipment, etc. is capable of releasing water at a rate of 1 000 m^3/s at the preliminary release level, i.e., 76.3 m in elevation.

We addressed several challenges, including countermeasures against the behavior of standing water in the tunnel during earthquakes (which is unique to tunnel spillways) and methods of performing various performance checks (e.g., water-tightness check) during the fabrication of large equipment.

5.2 Brief specifications of key facilities

Figure 10 provides an outline of the whole facility. The brief specifications of the respective components are given below.

(1) Main control gate

Type	High-pressure radial gate
Clear span	4.200 m
Effective height	7.500 m
Gate leaf radius	14.000 m
Water seal type	Upstream seal type square rubber water seal (B3)
Open/close unit	Hydraulic cylinder (with intermediate trunnion mount)

(2) Guard gates

Type	High-pressure slide gate
Clear span	4.200 m
Effective height	8.133 m
Water seal type	Downstream seal type
Open/close unit	Fixed hydraulic cylinder type

(3) Transition pipe

Type	Steel stiffener and dowel type
Intake diameter	ϕ 11.500 m
Outlet diameter (width × pipe height)	13.400 m × 11.500 m
Pipe length	11.500 m

(4) Branch pipe and bell mouth pipe

Type	Steel stiffener and dowel type

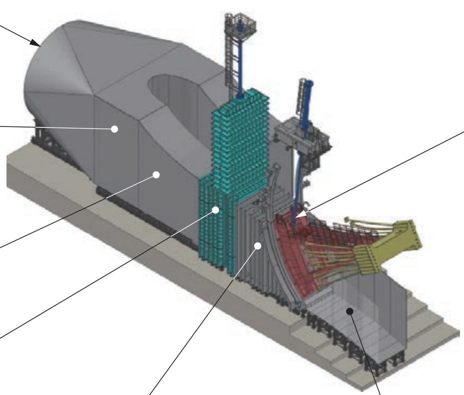

Fig. 10 Outline of the whole facility

Intake diameter (width × pipe height)
13.400 m × 11.500 m
Outlet diameter (width × pipe height)
4.200 m × 8.400 m (2 pieces)
Pipe length 16.500 m

(5) Gate section discharge pipe
Type Steel girder type
Intake diameter (width × pipe height)
4.200 m × 7.904 7 m
Outlet diameter (width × pipe height)
4.200 m × 7.500 m
Pipe length 8.950 m

(6) Current plate
Type Steel stiffener and dowel type
Intake diameter (width × pipe height)
4.200 m × 9.000 m
Outlet diameter (width × pipe height)
4.200 m × 7.494 m
Channel length 11.000 m

5.3 Key points for addressing challenges

5.3.1 Design conditions allowing for large-scale earthquakes

We conducted a study assuming that this spillway gate equipment installed in the outlet section of the tunnel spillway would be struck by a large-scale earthquake. As a result, it was revealed that the rigidity of the gate leaf of the main control gate, if allowing for dynamic water pressure acting on the main control gate attributable to standing water in the tunnel, would need to be extremely high and therefore substantially compromise the cost efficiency of the design. For this reason, the operation method was reviewed and it was decided to keep the interior of the tunnel in a dry state at normal condition, by using the gate installed in the outlet section of the tunnel spillway (beyond the scope of this project) to cut off incoming water. Consequently, it was ensured that there would be no water in the tunnel at normal condition. Hence, dynamic water pressure during earthquakes was disregarded in the design.

5.3.2 Pressure resistance test of guard gates at factory

Since the structure was designed to ensure watertight between blocks of the casing and bonnet by means of sealing run welding after on-site assembly in consideration of the gate dimensions, it was extremely difficult to conduct a pressure resistance test during temporary assembly at the factory. For this reason, we conducted finite element method (FEM) analysis instead of a pressure resistance test and ascertained how the joints and gate leaf seals would deform when subjected to water pressure at the installation site, thereby assuring validity (we adopted this method also for the outlet gates of the Tsuruda Dam described in **Chapter 3**).

6. Conclusion

This article has reviewed previous redevelopment projects from the perspective of upgrading existing dams and presented core technologies. Specifically, it has described ① installation of facilities putting no major load on existing dams; ② techniques for executing underwater work necessary to execute works on in-service dams; ③ techniques for accelerating operations in coordination with concurrent associated works; ④ techniques for quality control under tough conditions; and more.

Amid a decrease in new dam development projects, it is anticipated that the demand for upgrading existing dams will continue to grow from now on. In addition, we are also looking to put these techniques to use in overseas projects in the future.

A dam upgrade project is an approach whereby existing facilities can be effectively utilized with a small investment to achieve great benefit. As a leader in the manufacture of gate equipment, we will commit ourselves to continuing to contribute to the further promotion of dam upgrade projects through our continuing development of engineering technologies capable of accommodating even severer conditions and other activities.

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