□ **Project Effectiveness Analysis**

| | Before | | | | | After | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Duration (hr) | Rainfall (mm) | Inflow ($m^3/s$) | Outflow ($m^3/s$) | Ellevation (m) | Duration (hr) | Rainfall (mm) | Inflow ($m^3/s$) | Outflow ($m^3/s$) | Ellevation (m) |
| PMF | 24 | 630 | 8,354 | 6,656 | 200.34 | **18** | **559** | **8,601** | **7,758** | **198.18** |

## 5. Conclusion

Seomjingang dam's rehabilitation project involved complex construction for the purpose of securing additional water resources through the normalization of dam operations and by installing an auxiliary spillway. This has resolved flood risks and by relocating residents, there safety has been ensured. Also, we adjusted the dam's elevation normally and re-evaluated the water supply capacity by analyzing recent sluice data. This project has resolve downstream water shortages and has contribute to the revitalization of the downstream ecosystem. Also, this project does not contradict with negative opinion about dam construction and could secure water resource safely. This is a perfect example of a win-win situation in that this project is in harmony with water resource development and environmental conservation.





# EAST ASIA SYMPOSIUM
# REDEVELOPMENT OF THE LARGEST DAM IN JAPAN
# – Construction to Redevelop Tsuruda Dam Facilities –

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## ABSTRACT

The Tsuruda Dam redevelopment project is the largest redevelopment work ever executed in Japan. To perform the work efficiently, we developed new technologies: the underwater concrete placing system and the floating temporary cofferdam. This paper reports on the plan for the redevelopment of the Tsuruda Dam and introduces the status of work to reconstruct the facilities of the Tsuruda Dam.

*Keywords*: dam redevelopment, increase flood storage, dam-body drilling, cofferdam

## 1 INTRODUCTION

Tsuruda Dam was completed in 1966 as a concrete gravity dam in almost the center of Sendaigawa, the second longest river in Kyushu, and approximately 51 km from the estuary built for the purpose of flood control and power generation. Figure 1 shows the location of Tsuruda Dam, and Table 1 and 2 show the specifications of the dam and reservoir.


Figure 1 Location of Tsuruda Dam

Table 1 Dam Specifications

| Item | Specifications |
|---|---|
| Type | Concrete gravity dam |
| Height | 117.5 m |
| Length | 450.0 m |
| Volume | 1,119,000 $m^3$ |

Table 2 Reservoir Specifications

| Item | Specifications |
|---|---|
| Catchment area | 805.0 $km^2$ |
| Reservoir area | 3.61 $km^2$ |
| Reservoir capacity | 123,000,000 $m^3$ |
| Effective storage capacity | 77,500,000 $m^3$ |
| Flood capacity | 75,000,000 $m^3$ |
| Normal water level | Altitude 160.0 m |
| Lowest water level | Altitude 130.0 m |

After the severe damage caused by record rain in July 2006, the redevelopment of Tsuruda Dam started in 2007 to reduce damage caused by flooding in the Sendaigawa valley.

The concept of the project, as shown in Figure 2, is to increase flood capacity and discharge facilities. The increase in flood storage will increase to a total capacity of between 75 million $m^3$ and 98 million $m^3$ by transferring the power generation capacity during flood season of 2.5 million $m^3$ and dead water storage of 20.5 million $m^3$, for a total of 23 million $m^3$, to flood storage.

The discharge facility was expanded to enhance discharge capacity by adding three conduit gates on the right dam-body (EL 115.6) at a location lower than the current discharge facility (EL 130.0) in accordance with the decline of the lowest water level. The specifications of the expanded discharge facility are shown in Table 3.

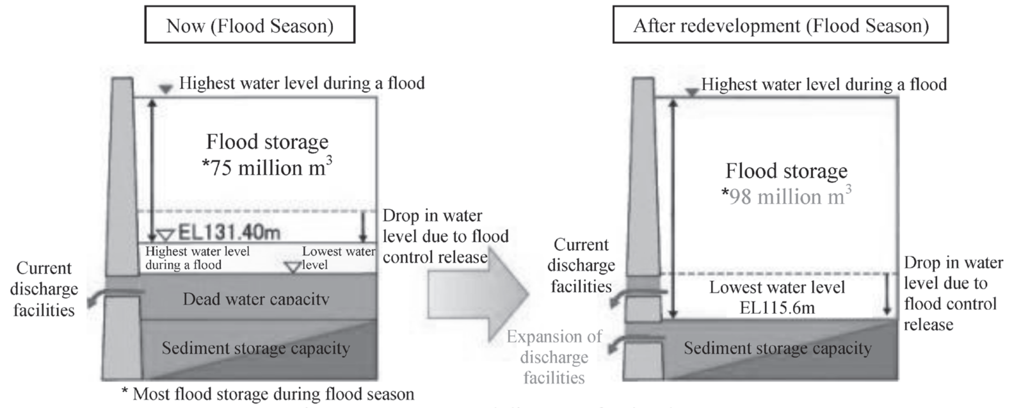



Figure 2 A conceptual diagram of redevelopment

Table 3 Specifications of the expanded discharge facility

| Item | Specifications |
|---|---|
| Conduit gate | Height 4.8 m × Width 3.4 m × 2 gates<br>Height 3.8 m × Width 2.8 m × 1 gate |

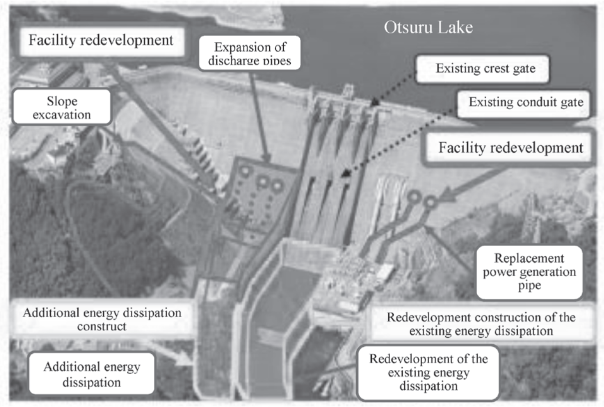
## 2. OVERVIEW OF THE REDEVELOPMENT

The construction range for redevelopment is shown in Figure 3. There are three steps of construction, and facility redevelopment is the first step. The main construction work will be pedestal concrete (upriver cofferdam), additional energy dissipation (upriver concrete), and dam-body drilling. The amount of major construction is shown in Table 4.

The second step of construction is additional energy dissipation (downstream concrete), installation of discharge pipes, and power generation intake pipes (lined concrete). The third step is the redevelopment of the existing energy dissipation.








Picture 3 Construction range for redevelopment

Table 4 Amount of main construction to redevelop the facility

| Type | Details | Unit | Qty | Remarks |
|---|---|---|---|---|
| Cofferdam pedestal | Drilling (includes removal of footing) | $m^3$ | 1,520 | |
| | Underwater inseparable concrete | $m^3$ | 1,990 | Expansion 1<br>Power generator 2 |
| Additional energy dissipation | Excavating stones and bedrock | $m^3$ | 217,000 | |
| | Concrete | $m^3$ | 69,700 | |
| Dam-body drilling | Discharge pipe extension | $m^3$ | 6,450 | 6.0 m × 6.0 m<br>3 streams |
| | Power generation intake pipe | $m^3$ | 4,460 | 6.2 m × 6.2 m<br>2 streams |

## 3. MAIN CONSTRUCTION TYPES AND METHODS FOR REDEVELOPMENT

### 1.1 CONSTRUCTION WHILE CONTINUING THE EXISTING FUNCTIONS OF THE DAM

As this construction is being conducted while continuing the water control and power generation functions of the dam, construction restrictions were placed on reservoir water level and the construction period. To be more precise, the construction was planned during a non-flood-prone period: October 16 to June 10. Construction up to the installation of the upstream cofferdam in the reservoir was planned at a reservoir level altitude of 133 m — the least necessary to generate power — and construction within the upstream cofferdam was planned once the reservoir level was reduced to an altitude of 120 m to ensure maximum safety. The construction steps from temporary work to the upstream cofferdam are shown in Figure 4.

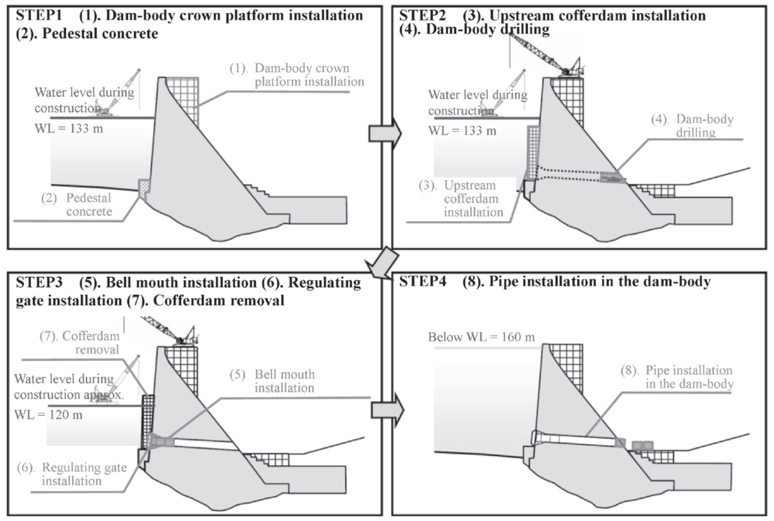



Figure 4 Construction steps in the reservoir

## 1.2 USING THE SATURATION DIVING TECHNIQUE

As the work in the water would be conducted at a depth of 65 m at the deepest, the saturation diving technique was used in order to ensure diver safety and work efficiency.

Saturation diving is a technique in which divers live in a space with the same level of pressure as the work during the construction period and decompress when they have completed construction work. The high-pressure environment from the living space to the work depth is maintained by using a bell (Figure 5).

Basic working hours are six hours a day and one crew's work period consists of 28 days, which are 24 days of actual work and 4 days of decompression. Moreover, divers are not to engage in diving work for one month after decompression as a safety measure.

During the entire construction period—October 2012 to March 2014 (excluding the flood season from June to September)—including the upstream cofferdam work conducted by equipment manufacturers, there was no decompression sickness observed and thus this is a diving method that ensures safety.

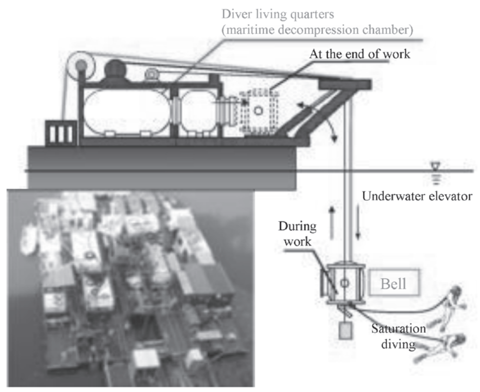



Figure 5 Conceptual diagram of saturation diving





## 1.3 PEDESTAL CONCRETE CONSTRUCTION WORK FOR THE UPSTREAM COFFERDAM

### 1.3.1 DRILLING IN WATER

To drill bedrocks and remove the footing in a maximum of 65 m of water, mechanized construction with an "all-casing drill" (Figure 6) was adopted to ensure reliability of construction work and reduce the burden on diving work. The central position coordinate of the drilling location was set in advance and drilling began after determining the location based on GPS installed on the barge.

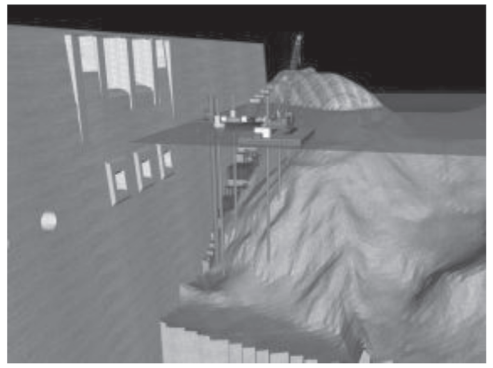


Figure 6 Illustration of drilling with an all-casing drill

### 1.3.2 PEDESTAL FORMWORK

For the pedestal concrete formwork, a method to comprehensively install an independent large panel form with steel pipe piles was adopted. The form was installed after drilling the bedrock and casing pipes were placed by suspending the large scale panel form that was assembled on the dam-body crown platform with a crane while the GPS and saturation divers checked the position. Picture 1 shows how the installation took place.

Picture 1 Installation of the large panel form

### 1.3.3 CONCRETE PLACEMENT

As shown in Figure 7, concrete was pneumatically fed by a concrete pump installed on the dam-body crown. Moreover, the flow distance was controlled for less than 5m to ensure inseparability by managing the pour position using GPS.

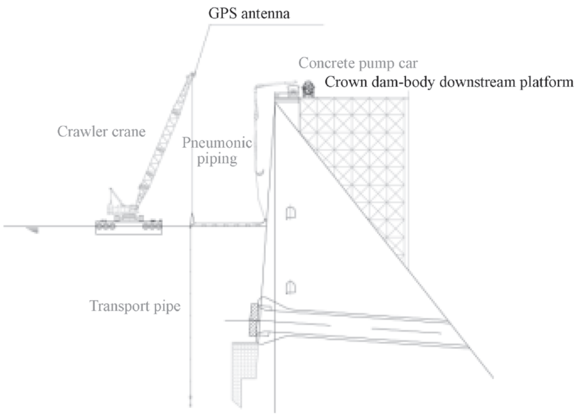



Figure 7 Direct pouring with a concrete pump

## 1.4 DAM-BODY DRILLING

### 1.4.1 OVERVIEW OF DAM-BODY DRILLING

In the existing dam, a total five holes were drilled: three for the expansion of discharge pipes and two to move the power generation intake pipes. As shown in Figure 8, the drilling depth per hole is 60 m, which contains a section of 1 m of upstream non-vibration penetration (section size: vertical 6 m × horizontal 6 m). To drill the general section, a 200 to 240 kW class road header was used. Picture 2 shows the drilling work performed by a road header.

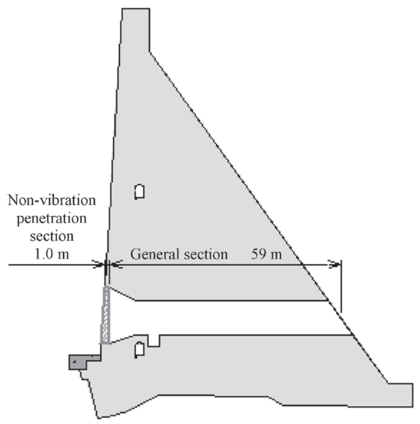
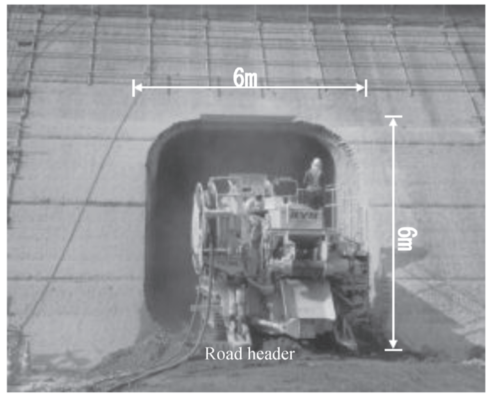



Figure 8 Longitudinal profile of the drilled dam-body








Picture 2 Drilling the dam-body

### 1.4.2 OVERVIEW OF THE NON-VIBRATION PENETRATION METHOD

This drilling work is the largest of its kind in Japan and therefore it was necessary to consider the impact on surrounding equipment, such as the gates built for drilling and the cofferdam. As it was reported from similar construction that vibration would be the strongest at the time of penetration, the non-vibration penetration technique was adopted to avoid impact from vibration during penetration. Figure 9 shows the construction overview. This is a penetration technique that cuts and divides the dam-body into blocks with a wire saw, and in the actual construction work, the dam wall was divided into 16 parts (four lines x four levels) based on the capability of the crane used in this construction and the size of the penetration section. After draining the water out of the cofferdam, an assembly platform is installed in the cofferdam for dividing work and concrete block withdrawal. Core boring is then performed on the surrounding top half of the penetrating part (top half) to separate it, and is divided into eight blocks (four lines × two levels) with a wire saw and cut while penetrating. The cut concrete blocks (2.5 m × 2.5 m) are pulled onto the assembly platform with a lever block and transferred to the dam-body crown with a crane. Picture 3 shows how the block is transferred.

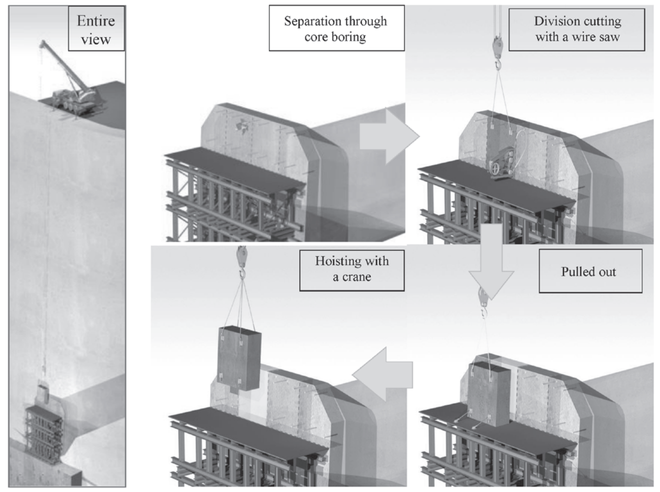
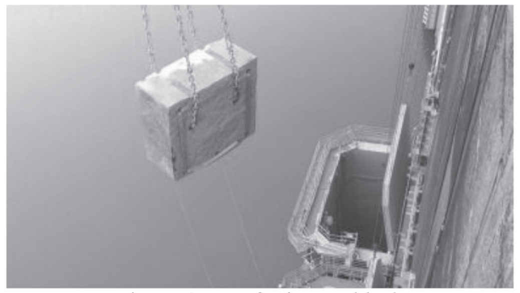



Figure 9 Overview of the non-vibration penetration technique



Picture 3 Transferring cut block

After the construction work is complete for the top half, the same technique is applied to the underside half (bottom half).

## 4. DEVELOPING NEW TECHNOLOGIES

The Ministry of Land, Infrastructure, Transport and Tourism Kyushu Regional Bureau, Japan Dam Engineering Center, Kajima Corporation, and Hitachi Zosen Corporation have jointly developed a new technology for the cofferdam, called the “floating type temporary cofferdam method,” for the dam redevelopment, and this new method was used for the first time in the Tsuruda Dam redevelopment.

### 4.1 BACKGROUND OF THE DEVELOPMENT OF THE TECHNOLOGY

When opening new holes in the dam-body for the discharge conduit and gates while continuing the functions of water control and use, and maintaining the water level of the dam reservoir, a steel cofferdam will be installed to drain water from the inside and ensure a dry space for construction. Conventionally, there are broadly two types of cofferdam methods: the pedestal concrete method and the support frame method (see Figure 10). However, both methods required long diving hours at a very deep water depth, large temporary equipment, and a long construction timeframe.

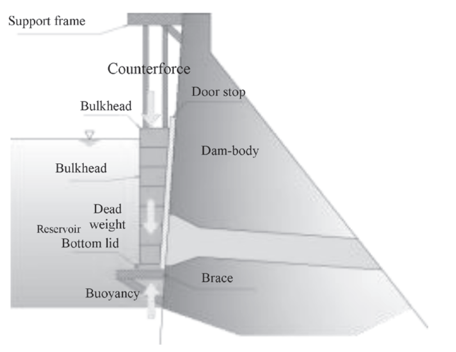
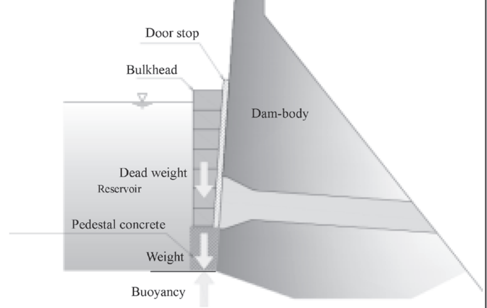
| | Support frame cofferdam method (conventional method) | Pedestal concrete cofferdam method (conventional method) |
|---|---|---|
| Structure |  |  |
| Features | ・Install braces and support frame to support the barrier before installing the cofferdam<br>・Bear the bulkhead weight during assembly with a support frame and brace<br>・Install steel bottom lid as there is no pedestal concrete<br>・Install bulkheads one by one on the bottom lid<br>・“Cofferdam dead weight + top part supporting frame” resist the buoyancy force when draining water from the cofferdam | ・Dredge and drill bedrocks before installing cofferdam to pour pedestal concrete<br>・After pouring concrete, install bulkheads one by one on the concrete base<br>・“Cofferdam dead weight + pedestal concrete weight” resists the buoyancy force after draining water from the cofferdam |

Figure 10 Overview of conventional cofferdam methods

### 4.2 OVERVIEW OF NEW TECHNOLOGIES

For the floating type temporary cofferdam method, steel plates (skin plates) are attached to both the inside and outside of the bulkhead to make an airtight structure, and this becomes the buoyancy chamber to make the bulkhead float. Meanwhile, the buoyancy force that interacts with cofferdam is supported by installing an anti-buoyancy brace on the dam-body of top barrier. Cut-off performance is ensured as the rubber attached to the bulkhead when water is drained from the cofferdam presses against the pre-installed doorstop by water pressure. Figure 11 shows the comparison between the conventional method and the floating type method.

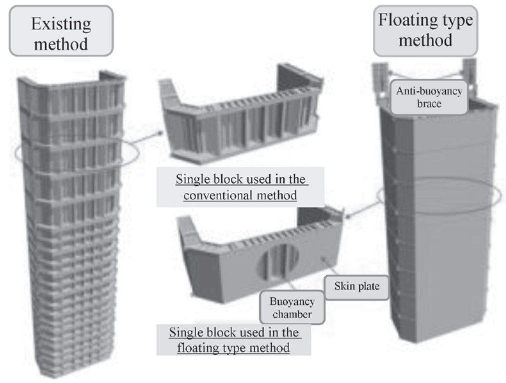



Figure 11 Bulkhead structure comparisons between conventional method and floating type method

For actual construction, bulkhead blocks made at local factories will be assembled on the reservoir to standardize them and they will be towed to the installation position by a ship, and subsequently pulled by a winch and secured. Figure 12 shows the assembly and installation methods, and Picture 4 shows installation at Tsuruda Dam.

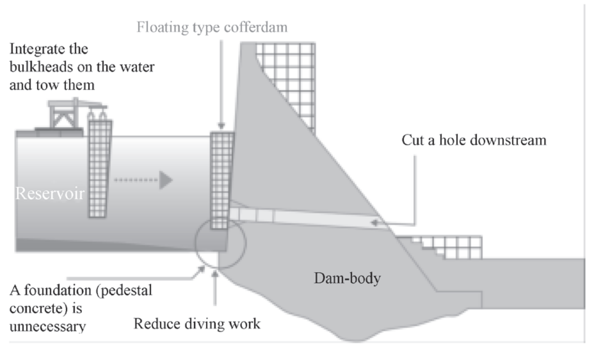



Figure 12 Assembly and installation overview

Picture 4 Floating type cofferdam installation

As the cofferdam equipment is installed in a U-shape to ensure working space, only one side floats and it would not be possible to maintain balance if buoyancy force is simply applied to the bulkhead. Therefore, it is important to maintain the balance between buoyancy forces and dead weight by filling and draining the bulkheads blocks in the proper order (see Figure 13). A countermeasure is to simulate bulkhead position when filling and draining the airtight room in the bulkhead block to find an order for filling and draining water that can maintain the balance of buoyancy force and its own weight.

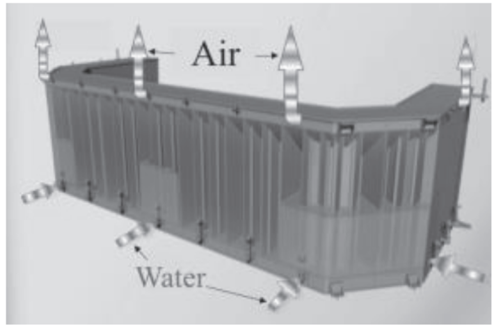



Figure 13 Filling and draining the bulkhead

### 4.3 CHARACTERISTICS OF THIS CONSTRUCTION METHOD

#### 4.3.1 REALIZATION OF IMPROVEMENT IN CONSTRUCTION EFFICIENCY AND SAFETY

As large temporary facilities, such as pedestal concrete and support framework, are unnecessary and diving work can be greatly reduced, costs and processes can be reduced, and safety can be improved, leading to an increase in construction efficiency. Moreover, when drilling holes in the same dam, it is necessary with conventional methods to dissemble and then reassemble the bulkheads, but with this method there is no need to disassemble the bulkheads; flood the cofferdam and detach the bulkheads from the dam-body and tow it as is to the next construction site where it can be installed.

#### 4.3.2 IMPROVING WATER TIGHTNESS

As a bulkhead block can be assembled out of the water, the collapsed state of the water tight rubber can be checked, reducing the amount of leakage between bulkhead blocks and improving water tightness.



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#### 4.3.3 REDUCING THE BURDEN ON THE ENVIRONMENT

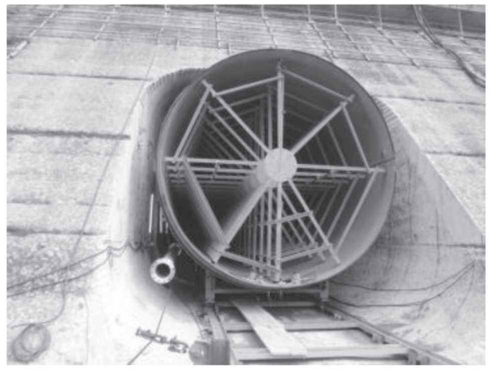
As pedestal concrete is unnecessary, there is no polluted water and industrial waste from dredging or foundation excavation in the reservoir.

### 4.4 APPLICABLE RANGE

It can be applied to drilling a new hole in the dam and installing an effluent pipe or gate as a cofferdam for redevelopment construction, regardless of dam size, number of holes, or construction depth. However, it cannot be applied if the water level of the reservoir is lower than the lowest level in the past, or if there is an obstruction blocking the tow that cannot be removed.

## 5. PROGRESS STATUS OF CONSTRUCTION

Preparatory work started in February 2011; for construction in the reservoir, Generator 1 was installed in April 2012, Expansions 1 and 2 were added in October, and pouring pedestal concrete for Generator 2 was completed in April 2014. 69,700 $m^3$of concrete for energy dissipation extension work, the target of this construction, was poured in March 2013. Three dam holes—Expansion 2 and 3, and Generator 1—were completed in November 2013. Currently, drilling is underway for two holes for Expansion 1 and Generator 2, and is scheduled to be completed in November 2014. Drilling holes for Expansion 1 and Generator 2 that were scheduled for this financial year for the upstream cofferdam have been installed, and water will begin to be drained from the middle of October. The installation in the dam-body and pouring of backfill concrete for the discharge pipe Expansion 2 and 3 is complete. Currently, the external section of the dam-body for Discharge Pipe 3 and the main gate are being installed. The current state of installation is shown in Picture 15. Installation of the intake pipe and pouring of backfill concrete is complete.



Picture 15 Discharge Pipe Expansion 3 installation status

The state as of the end of August 2014 is shown in Picture 6

Picture 6 Aerial photograph taken at the end of August 2014