TEMPORARY STREAM DIVERSION FOR THE OYUBARI DAM REDEVELOPMENT PROJECT

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ABSTRACT

This paper reports issues and solutions associated with temporary water diversion systems for dam construction, including the diversion method, and design and construction of diversion structures. The Oyubari Dam Redevelopment Project is currently underway to meet the increasing water demand and to prevent flood damage. Under this project, a new dam, the Yubari Shuparo Dam, is proposed to be constructed, 150 m downstream from the existing Oyubari Dam, which will increase the storage volume and level of the existing reservoir. The new dam is planned to be 110 m in height with a crest length of 390 m and a volume of 940,000 m^3 after completion in 2015, and the existing reservoir will be incorporated into the new reservoir afterward. The total storage capacity of the new reservoir is 427,000,000 m^3, which is about five times greater than that of the existing dam. The new dam will serve multiple purposes: flood control, maintenance and improvement of river functions, irrigation, water supply, and power generation. Meanwhile, the existing dam is primarily used for irrigation and power generation; therefore, water must be constantly released downstream from the reservoir during the new dam construction. To secure water supply and water level during dam construction, a temporary stream diversion was carried out two times—providing a diversion channel around the new dam—and four diversion tunnels were constructed through the base of the new dam to handle a design peak flood flow of 1,300 m^3/s from the existing dam.

INTRODUCTION

The Yubari Shuparo Dam (hereafter “the new dam”) is currently under construction in the south of Yubari City, Hokkaido, Japan. It is a concrete gravity dam located 155 m downstream of the Oyubari Dam (concrete gravity dam) (hereafter “the existing dam”), which was completed in 1962 (Table 1, Figures 1–3). The existing dam will be submerged in the reservoir of the new dam after the completion of the new dam, scheduled for 2015.

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Table 1. Profile of the Oyubari Dam and the Yubari Shuparo Dam.

Item	Oyubari Dam	Yubari Shuparo Dam
Purposes	Irrigation Power generation	Irrigation Power generation Water supply Flood control Maintenance and improvement of river function
Dam type	Concrete gravity	Concrete gravity
Dam height	67.5 m	110.6 m
Crest length	251.7 m	390.0 m
Volume of dam body	201,000 m^3	940,000 m^3
Reservoir area	4.75 km^2	15.0 km^2
Total storage capacity	87,200,000 m^3	427,000,000 m^3
Effective storage capacity	80,500,000 m^3	367,000,000 m^3
Design flood flow rate	1,300 m^3/s	3,000 m^3/s

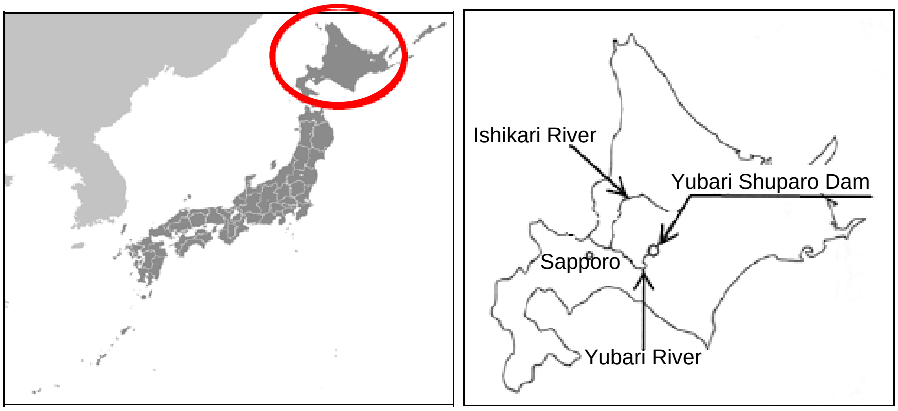

Figure 1. Project location map.

Figure 2. Location of the Yubari Shuparo Dam relative to the Oyubari Dam.

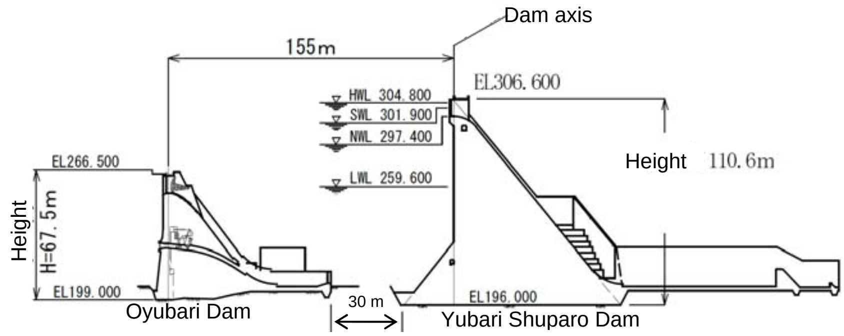

Figure 3. Specifications of the Oyubari Dam and the Yubari Shuparo Dam.

In 1980, the Ministry of Agriculture, Forestry and Fisheries (MAFF) formulated a plan to raise the existing dam by 13.3 m to better meet water demands for growing agricultural use. However, the following year, an unprecedented devastating flood struck the Ishikari River basin, and flood control issues emerged. This led to the planning of a new, multipurpose dam construction downstream of the existing dam. Surveys for this new facility began in 1991, and construction started in 1995 as a joint effort by the four commissioning parties, led primarily by the Comprehensive River Development Project of the Ministry of Land, Infrastructure, Transportation and Tourism and MAFF's Agricultural Land Improvement Project.

The new dam is planned to be 110 m in height with a crest length of 390 m and a volume of 940,000 m^3 when completed. The total storage capacity of the new reservoir is 427,000,000 m^3, which is about five times greater than that of the existing dam.

The Futamata Hydroelectric Power Plant, located immediately downstream of the existing dam, generates electricity using the water from the reservoir. Therefore, construction of the new dam must be carried out while maintaining the function of the existing dam and power plant (Figure 3).

BACKGROUND NOTES

Function of the Oyubari Dam

The existing dam is a concrete gravity dam, which was completed in 1962 under the National Irrigation and Drainage Project of Oyubari Dam Area as part of the Hokkaido Development Project. The primary functions of the dam are irrigation and power generation. Although the dam is not intended for flood control, it is provided with an emergency spillway to handle a design peak flood flow of 1,300 m^3/s. The design peak flow was determined on the basis of the probability of a flood occurring once every hundred years, with a maximum recorded flow of 855 m^3/s at the dam.

Irrigation water is supplied annually from April 20 to August 20 (at a maximum of 25 m^3/s), and almost 100% of the supplied water is used for agricultural purposes every year.

The dam takes advantage of water discharged for irrigation and generates electricity. To generate electricity, the hydroelectric power plant receives water at a rate of 7–32 m^3/s from the reservoir, which depends on agricultural water demand during the irrigation period.

The existing dam has three water discharge facilities consisting of the dam top spillway, the power plant outlet (taking water from a selective water intake facility), and the conduit at the base of the dam. Water is released from the hydroelectric power plant back into the stream after passing through turbines in the power plant in order to maintain optimal temperature range through irrigation period. This means irrigation water cannot be supplied if the power generation operation is suspended during dam construction. Irrigation water supply is required even during construction of the new dam. Taking into account water utilization, a temporary stream diversion was planned to meet the following two key conditions: (1) to not suspend power generation throughout dam construction for water supply during irrigation period, and (2) to ensure a discharge capacity of 1,300 m^3/s to manage risk of flooding to the power plant.

CHALLENGES IN STREAM DIVERSION PLAN

Diversion flow rate

In general, the diversion flow rate during construction of a concrete dam is determined on the basis of the probability of a flood occurring once every two years. In line with this idea, the theoretical diversion flow for this project was assumed to be 390 m^3/s. However, if the flood water volume had exceeded the discharge capacity of the existing dam, the water would have been held behind the new dam and would have raised the water level. The Futamata Hydroelectric Power Plant would have been subsequently submerged in the water, and the supply of irrigation water would have ceased (Figure 4). Therefore, the diversion flow was determined as 1,300 m^3/s, which was equivalent to the spillway discharge capacity of the existing dam.

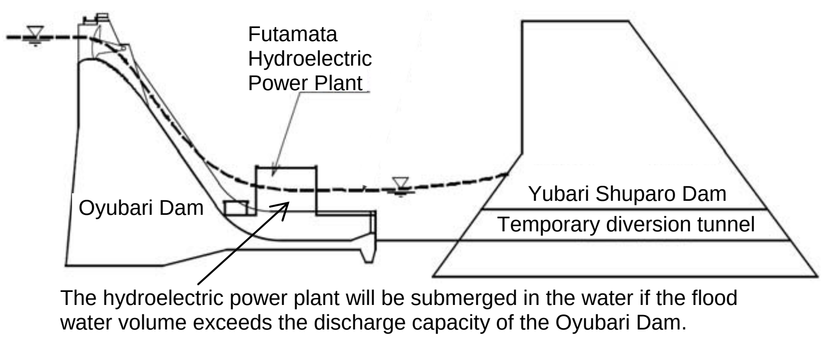

Figure 4. Schematic diagram showing the consequence of flooding.

Selecting a temporary stream diversion method

One commonly used temporary stream diversion method for dam redevelopment is to provide a temporary bypass tunnel downstream from the reservoir. This is effective when the riverbed is narrow. It also allows the existing dam and hydropower plant to maintain their functions during dam construction. This diversion method provides a larger construction area of the riverbed and minimizes the number of stream diversions. However, regarding this project, a large cross section was assumed to be required to provide a diversion flow of 1,300 m^3/s.

Therefore, an alternative method, which utilized the distance of about 30 m between the Futamata Hydroelectric Power Plant and the new dam, was proposed and examined. This method implemented temporary stream diversions two times: the primary diversion and secondary diversion provided an open diversion channel around the new dam, and four diversion tunnels were constructed through the base of the new dam (Figure 5). This method is called the Semi-Closing River Method. The feasibility of this method was tested using a 1:40-scale hydraulic model, which confirmed its capability of handling 1,300 m^3/s water discharged from the existing dam.

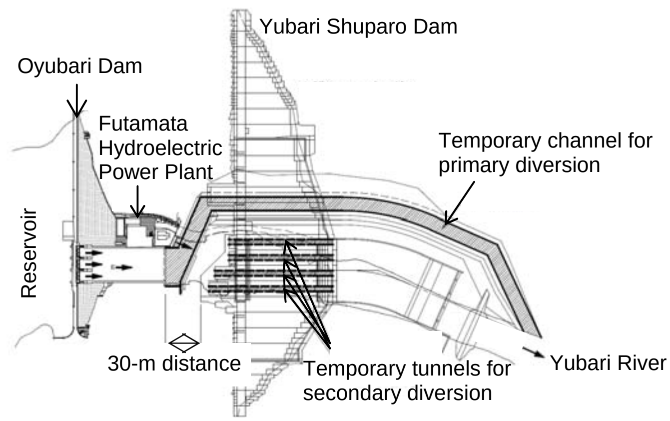

Figure 5. Layout of the stream diversion structures.

In addition to the technical feasibility, the economic aspects of the two methods—the bypass tunnel method and the Semi-Closing River Method—were compared and examined, and the latter method was selected for the project.

Layout of the temporary stream diversion structure

The layout of the primary diversion structure and the secondary diversion structure are shown in Figure 6.

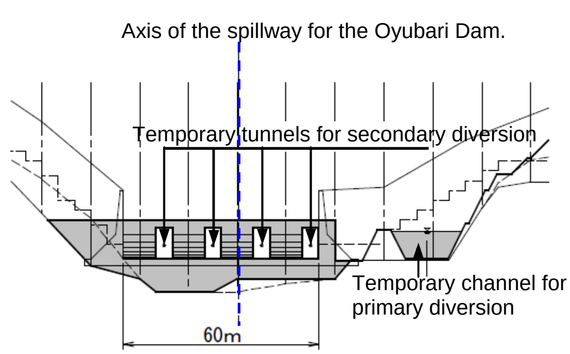

Figure 6. Cross-sectional view of diversion structures (facing up stream).

Primary stream diversion. For the primary diversion, a concrete wall (herein after referred to as "retaining wall") was constructed just downstream of the existing dam to divert the stream to the left bank (facing downstream). The temporary diversion channel was constructed along with the excavation of dam foundation rock for the new dam. Key considerations for determining the layout of the diversion channel were as follows:

• To not affect construction of the new dam body and spillway,
• To keep flood water out of the Futamata Hydroelectric Power Plant even during the 1,300 m^3/s flood peak discharge, and

• To site the diversion channel within the foundation excavation area as much as possible.

Secondary stream diversion. The secondary diversion structure was composed of a connecting waterway, diversion tunnels through the base of the new dam, and a downstream waterway. The stream was shifted to the diversion tunnels through the connecting waterway by removing the retaining wall used for the primary diversion. The cross-sectional area of the four diversion tunnels in the dam body was 5 m in width and 8.5 m in height. The total flow capacity was secured at 1,300 m^3/s. Key considerations for designing the diversion channels included the following:

To align the center of the four conduit tunnels to the center of the spillway to ensure a smooth flow of water, and

• To site all four diversion tunnels within the spillway.

The occurrence of an unstable hydraulic jump and asymmetric rotational flow at a flow rate of 1,300 m^3/s was observed by hydraulic-scale model experiments. Solutions for the unfavorable flow regime were sought in the diversion structure and the downstream water level based on the experimental results. It was decided to leave a part of the retaining wall used for the primary diversion and to construct a part of the secondary dam for the new dam in advance (Figure 7).

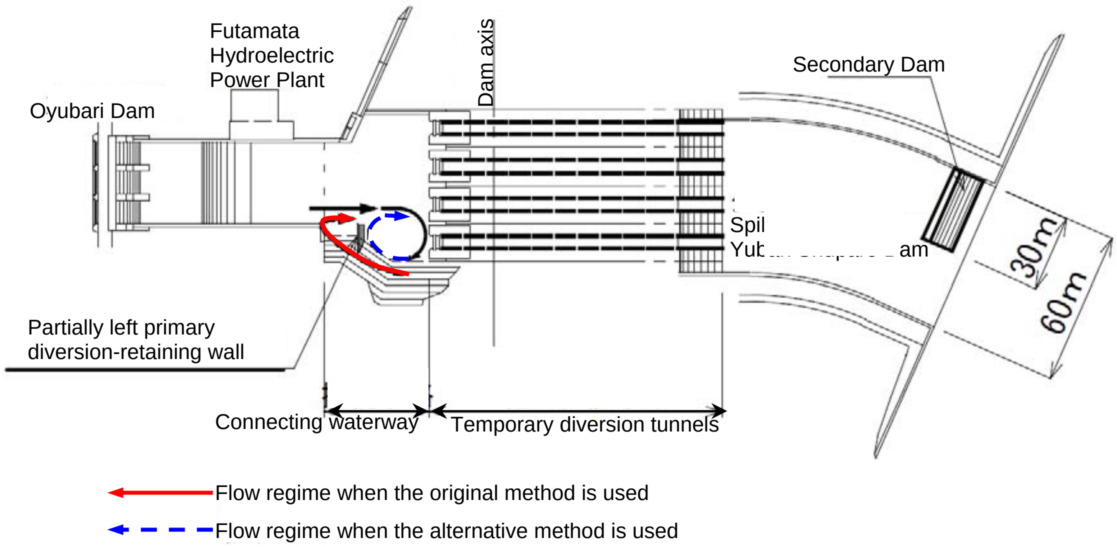

Figure 7. Layout of the secondary diversion structures.

The alternative design was tested using a scale model, and it confirmed the improvement of flow regimes. Water flow stability was maintained, and there was no effect on the discharge capability due to the partially built secondary dam.

CONSTRUCTION OF DIVERSION STRUCTURES

Following construction of the diversion channel for the primary diversion in December 2004, excavation of the right bank of the riverbed (facing downstream), began in 2006. In 2008, construction of the diversion tunnels through the new dam body for the secondary diversion started. After the completion of the diversion tunnels in March 2009, the retaining wall used for the primary diversion was removed, and stream flow was shifted from the primary diversion channel to the secondary diversion tunnels. Key topics covered in this section include construction of the secondary diversion tunnels, preliminary work prior to secondary diversion, and an overview of the closure of the secondary diversion tunnels scheduled for September 2013.

Construction of the temporary diversion tunnels

In general, it is difficult to directly transport concrete by a dump truck to peripheral structures such as conduit tunnels located in the dam body; therefore, a crane is commonly used. The construction plan for the temporary diversion tunnels through the base of the new dam included the following key considerations:

• Construction required a large concrete construction area about 60 m in width and 100 m in length.

• To implement the secondary stream diversion work, all discharges were required to be temporarily suspended; therefore, it had to be restricted to the winter, agricultural off-season.

• Mobility in the construction area was constrained since four diversion tunnels were constructed through the base of the dam body.

Considering the restrictions, it was difficult to use tower cranes or crawler cranes to transport concrete. These machines required large temporary facilities and could decrease working efficiency compared with transportation by dump trucks. Therefore, dump trucks were employed to transport concrete, in conjunction with a joint cutting method, between concrete blocks.

The width of 8 m between the temporary diversion tunnels (Figure 8 (a)) was sufficiently wide to offer 10-ton dump truck access to the construction site. Therefore, dump trucks were hoisted up by a crawler crane downstream and brought into the construction site, and then the concrete was transported by the dump trucks.

The use of precast concrete materials for the top and the bottom of the diversion tunnels reduced construction time (Figure 8 (b) and (c)). The construction progress of the secondary diversion channels is shown in Figure 9 from the beginning to the end of the construction.

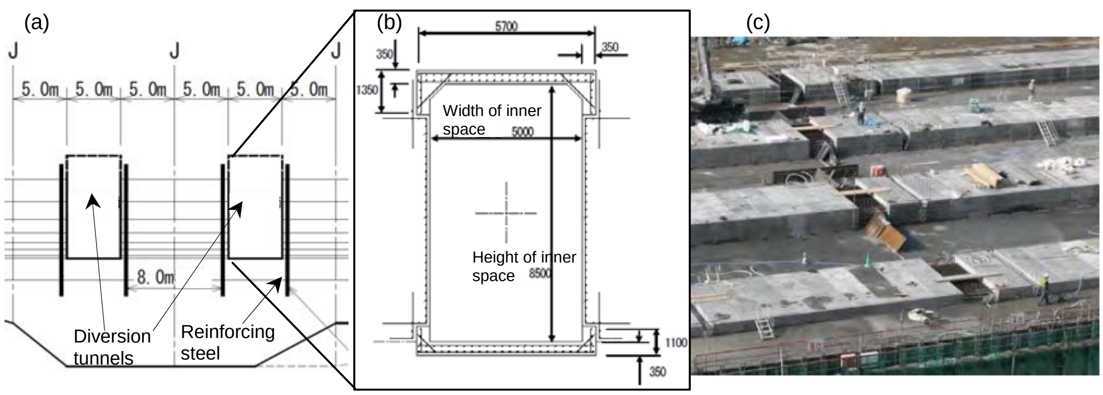

Figure 8. Cross section and precast concrete material used for the temporary diversion tunnels: (a) spacing between the tunnels, (b) precast concrete material used for the top and bottom of the tunnels, and (c) placing precast concrete materials at the top of the tunnels.

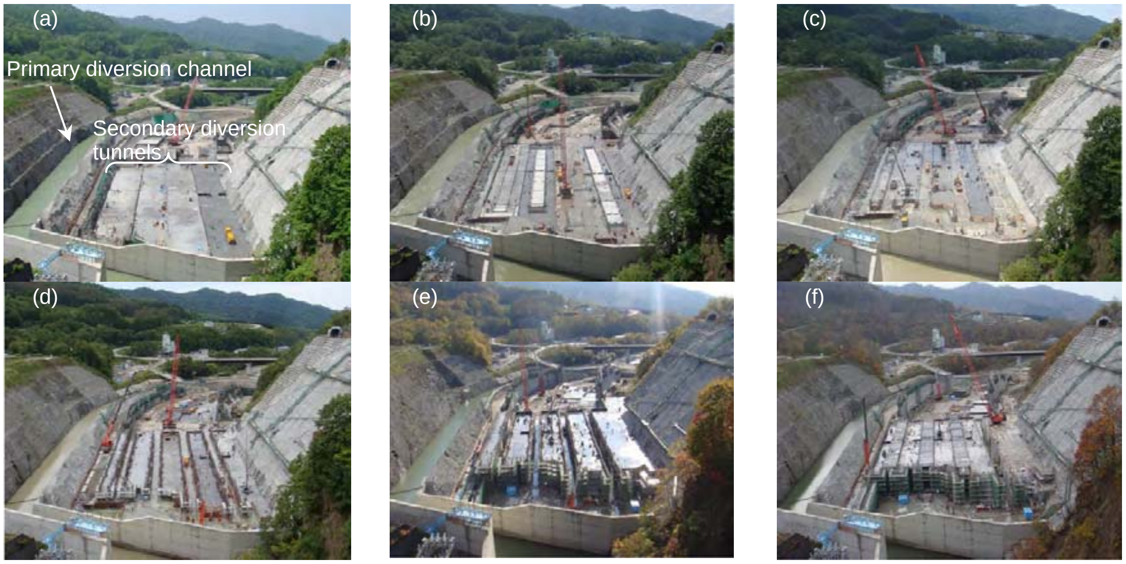

Figure 9. Construction progress of the secondary diversion structures from beginning (a) to end of the construction (f) (facing downstream).

Preliminary work prior to the secondary diversion

Switching the stream from the primary diversion channel to the secondary diversion tunnels was carried out from March 7, 2009, to March 21, 2009, when the power generation operation could be temporarily stopped with minimal impact on the area.

Prior to the secondary diversion, the upper part of the retaining wall (the height unaffected by discharges of 32 m^3/s from the power plant) used for the primary diversion was removed by March 6, 2009. Then, the rest of the retaining wall was removed during the 14 days when the power plant was temporarily shut down. In the same period, another concrete retaining wall was constructed at the inlet of the primary diversion channel to close the temporary channel, which had a height of 6 m and a volume of 252 m^3 (Figure 10).

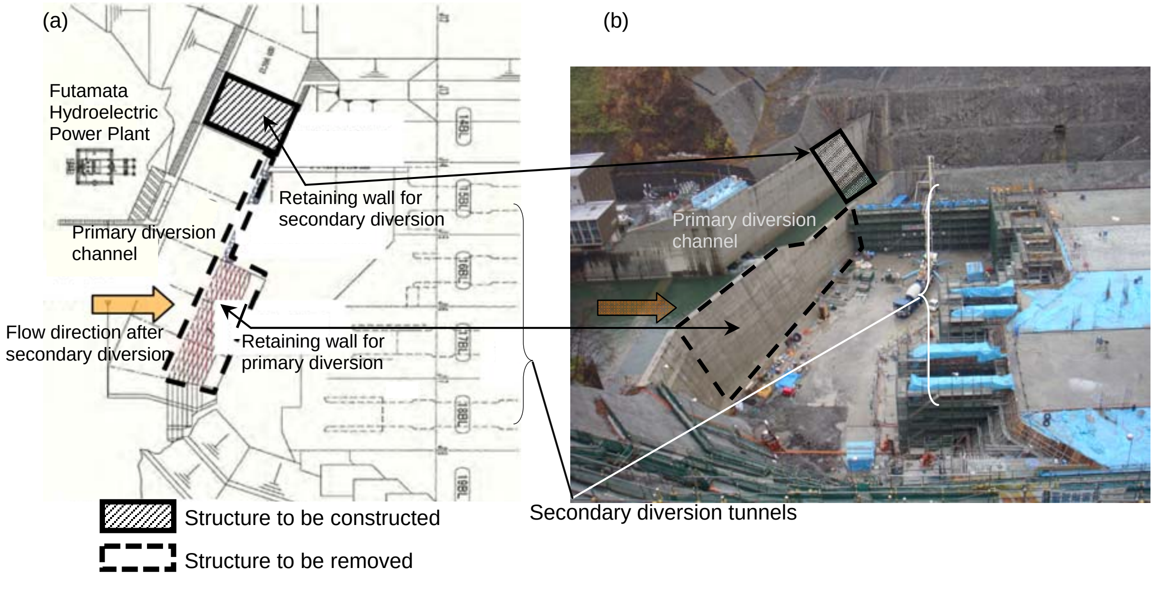

Figure 10. Layout (a) and construction (b) of the retaining walls for the primary and secondary diversions.

For the demolition of the retaining wall used for the primary diversion, the wire saw method was used. This method shortened the demolition process. In addition, it reduced stepping stones and the vibrations generated by machinery, which could affect the robustness of the power plant structure.

For transportation purposes, there was no option for heavy equipment and dump trucks used for the demolition of the retaining wall to use the diversion tunnels, where concrete curing took place over the winter. Therefore, gates were installed at both ends of the diversion tunnels to prevent cold air from entering the diversion tunnels and from causing cracks in the concrete. Figure 11 shows the construction site shortly after the secondary stream diversion following the demolition of the retaining wall used for the primary diversion.

Figure 11. Construction site after the demolition of the retaining wall used for the primary diversion (left) and shortly after the closure of the primary diversion channel (right) (facing downstream).

Closure of the temporary conduit tunnel

In March 2009, the stream was diverted to the secondary diversion tunnels from the primary diversion channel. Concrete construction was continued after the secondary diversion (Figure 12). Dam body concrete placement was completed in October 2012. Currently, dam construction is in the final phase and nearing completion.

In the first stage of the closure of the temporary diversion tunnels, the gates of the three diversion tunnels are closed, and the tunnels are filled and sealed with concrete prior to the impoundment test. In the second step, the fourth diversion tunnel gate will be shut down when the impoundment test starts. During the impoundment test, the fourth diversion tunnel will be completely filled up and sealed with concrete. The demolition of the Futamata Power Plant facilities and the existing dam gate will start after the irrigation period and will be completed by the start of the impoundment test. The closure of the three diversion tunnels is planned in parallel with the demolition of the retaining wall. These tasks must be completed within six months. Therefore, the construction schedule needs to be effectively and efficiently managed.

Figure 12. Progress of concrete placement for the Yubari Shuparo Dam in November 2011 (upstream surface).

CONCLUSION

For construction of a dam immediately downstream of an existing dam, it is important to consider specific circumstances. In the Yubari Shuparo Dam Redevelopment Project, it was necessary to maintain the functions of the existing dam. To meet these requirements, the project adopted the Semi-Closing River Method. This method employed a combination of primary stream diversion and secondary stream diversion, providing a temporary diversion channel around the new dam, and four diversion tunnels through the base of the new dam. To reduce construction time, the concrete retaining wall built for the primary diversion was removed using a wire saw, and precast concrete materials were selected for construction of the upper and lower part of the diversion tunnels. As a result, the secondary stream diversion was successfully undertaken on schedule. As of December 2012, the project is in the final phase toward the impoundment test, and the construction is proceeding with the greatest care.