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Water Quality Management by Free-selective Air-lock Intake

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ABSTRACT:

Selecting the intake depth of the reservoir is beneficial for quality management of the reservoir and water supply. This paper presents a selective intake system based on the air-lock method which can be operated and maintained easier than conventional systems.

The free-selective air-lock intake systems (another name: Continuous Siphon) are rapidly extended for these ten years. Nowadays, they are in operation at 5 dams, and under construction at 2 dams in Japan. Firstly, this paper describes these situations.

Secondly, this paper describes the basic study to validate the shape of intake tube which decided by hydrologic accounting. The loss coefficient affecting the shape of intake tube was validated to be 2.5 in this study using hydraulic model experiment and numerical model simulation. The results of model studies are also evaluated by comparing with the measurement results of one of the system in operation.

Thirdly, this paper presents the design and construction case of this intake system in Yubari-Shuparo dam located in the north Japan, which is the latest and one of the biggest systems completed. Its maximum amount intake water is $83m^3/s$ *and its range of intake depth is 45m.*

Additionally, this intake system in Yubari-Shuparo dam enabled to intake water from one or more tubes simultaneously, using inverse V-shaped tubes which are placed at different elevations, while the other intake tubes are stopped by air-locking. Further, this intake system realized the high economic performance by no use of multistage metal gates which include parts to be frequently maintained such as rubber sealants and wire ropes, no use of heavy steel structures and hoist equipment, and no tower structure on the dam crest.

Keywords: free-selective air-lock intake system, compressed air, air-lock, safe design

1. INTRODUCTION

1.1 Background

Selecting the depth of water intake is beneficial in managing the quality of water supplied from a dam. Water intake should ideally be positioned low in order to take water at all times from fluctuating reservoir water level. On the other hand, water at bottom of a reservoir may have negative impact on downstream environment for reasons such as excessively cold temperature or low level of dissolved oxygen.

In order to solve this problem, selective water intake system has been developed as a facility that freely changes the depth of water intake and predominantly takes surface water from fluctuating water level at reservoir.

However, conventional selective water intake system mainly uses steel multistage gate and hoist. This has resulted in extremely high construction cost for dams with large water intake volume and intake depth. Moreover, high cost is required for maintenance related to watertight rubber used at watertight area between each gate.

1.2 Free-selective Air-lock Intake System

The free-selective air-lock intake system is a new intake system with air-lock multistage continuous structure that has compressed air locked into reverse V-shaped pipe. It is an ingenious gateless water intake system in that it does not use any gates. The technology was initially developed in the 1990s as multistage air-lock selective intake system applied at Haji Dam. Since then, it has evolved into current shape as Continuous Siphon by placing intake pipes continuously and separating them with a partition.

As of February 2014, this intake system is already in use at five dams, i.e. Shitsumi Dam (Shimane), Obara Dam (Shimane), Tono Dam (Shimane), Kurokui Joryu Dam (Yamaguchi), Yunishigawa Dam (Tochigi). Construction work for this intake system is also under way at two dams, i.e. Yubari Shuparo Dam (Hokkaido) and Kirimegawa Dam (Wakayama). Both are scheduled to go into service in 2014.

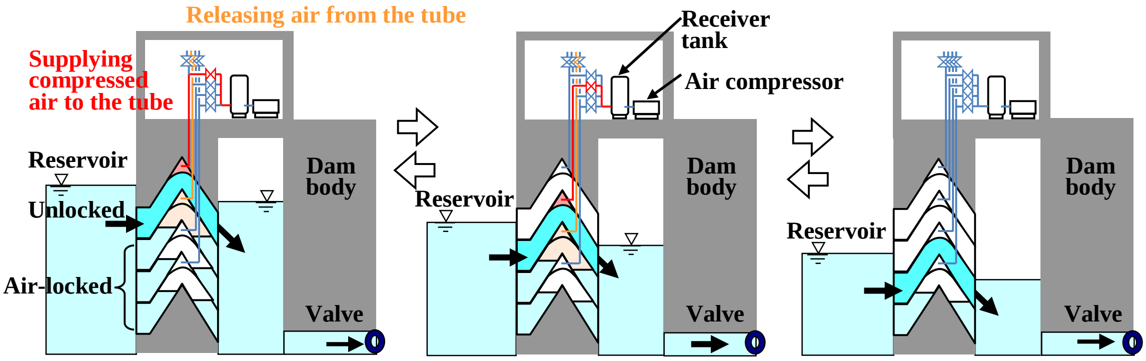

Figure 1. Conceptual diagram of the operation of free-selective air-lock intake system

2. FREE-SELECTIVE AIR-LOCK INTAKE SYSTEM

2.1 Basic Principle

The free-selective air-lock intake system uses steel reverse V-shaped intake pipe and air control unit. It makes intake possible from any water level as a result of air-locked condition created by passing water through intake pipe at any water level and filling other intake pipes with compressed air. Pneumatic control system consists of compressor, receiver tank, feed valve and exhaust valve. Opening the feed valve sends compressed air into intake pipe to perform air lock. Opening the exhaust valve releases the air inside intake pipe into atmosphere to pass the water.

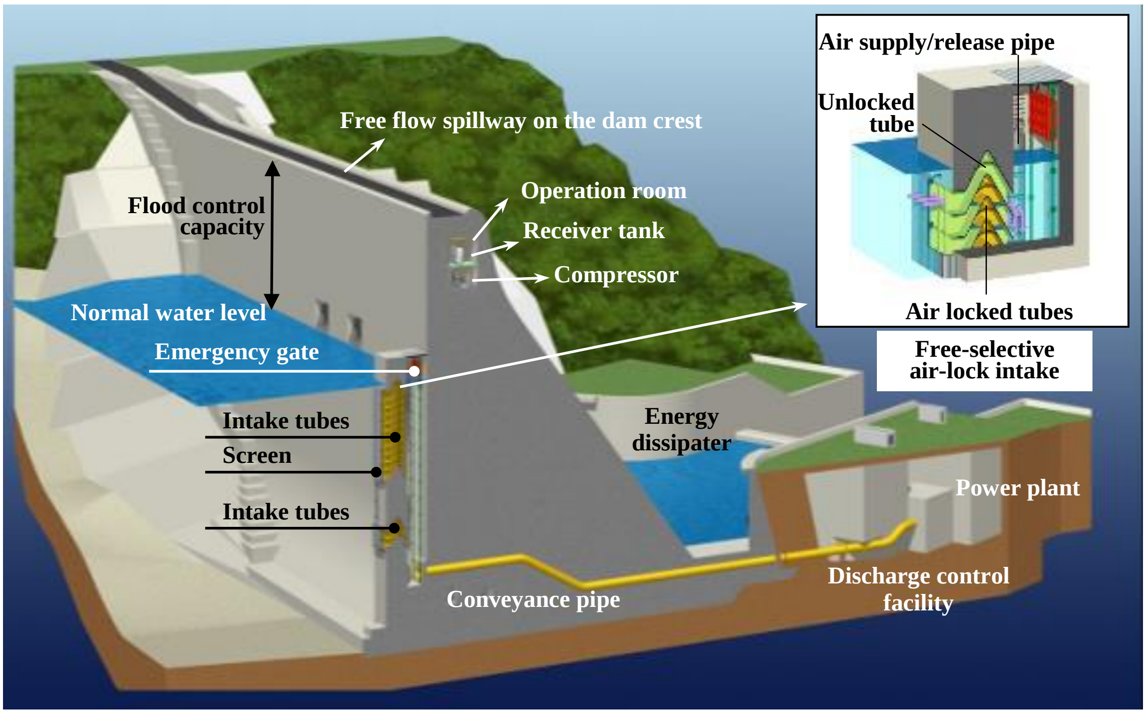

Figure 2. Conceptual diagram of free-selective air-lock intake system

3. BASIC RESEARCH RELATED TO THE SHAPE OF INTAKE PIPE

3.1 Difference in Water Level during Water Intake and Loss Coefficient

Water level difference d, which corresponds to head loss at intake pipe with flowing water, occurs inside and outside the intake tower of the free-selective air-lock intake system during water intake. This water level difference d coincides with difference in water level between upstream and downstream sections inside the air-locked intake pipe. Consideration is required when examining the shape of intake pipe so that upstream water level will not overflow from the highest point of intake pipe due to this difference in water level during normal operation.

Here, water level difference d can be expressed by formula (1) using loss coefficient f of intake pipe. Loss coefficient f is a coefficient determined by the pipe shape and roughness of pipe interior. Although it can be obtained by calculation based on hydrologic empirical formula, multifaceted verification through hydrologic experiments was required as it is a value that affects the basis of facility's function.

$$d = f\frac{v^2}{2g} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Whereas

d: Difference in water level during water intake

v: Flow velocity inside intake pipe

g: Gravitational acceleration

f: Loss coefficient at intake pipe

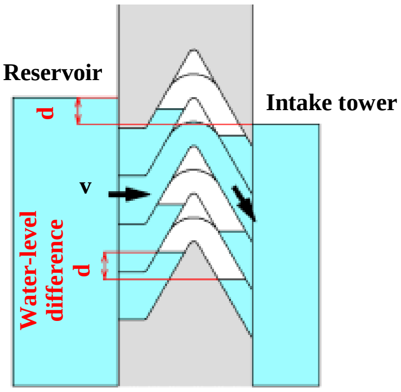

Figure 3. Conceptual diagram of water level difference during water intake

3.2 Verification of Loss Coefficient

3.2.1 Design Value of Loss Coefficient

Head loss from inflow and friction obtained from hydrologic accounting came to 2.2. However, loss coefficient was set at 2.5 to allow some leeway in the track of a similar precedent.

3.2.2 Hydrologic Model Experiment

One-tenth scale hydrologic model based on the free-selective air-lock intake system at Obara Dam was used for the experiment in order to verify the loss coefficient. Loss coefficient based on the results of hydrologic model experiment shown in Table 1 was 3.04.

Table 1. Loss coefficient at hydrologic model experiment

	1/1 0 model	Measured and converted values
Flow rate	0.025 m^3/s	8.0 m^3/s
Number of plates used	1	1
Intake pipe width	0.4m	4.0m
Intake pipe height	0.2m	2.0m
Flow speed	0.63 m/s	2.0 m/s
Difference in water level at water intake	0.062 m	0.62 m
Loss coefficient	-	3.04

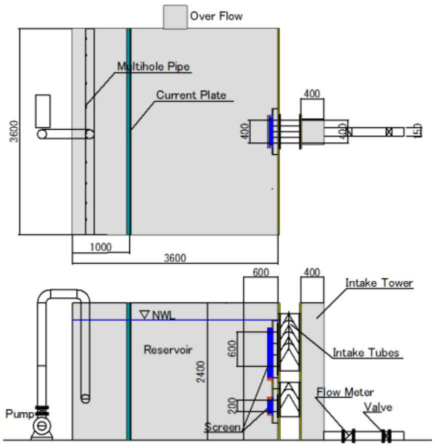

Figure 4. Hydraulic model

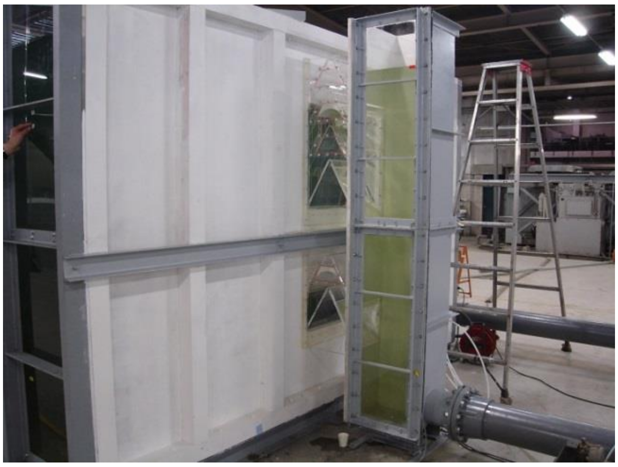

Figure 5. Photo of hydraulic model

3.2.3 Numerical Model Simulation

Numerical model simulation was conducted based on selective water intake facility at Shitsumi Dam in order to verify the loss coefficient. Difference in water level during water intake was calculated by simulation and was used to inversely calculate the loss coefficient.

The purpose of conducting this numerical model simulation lies in grasping the deviation of loss coefficient in numerical model simulation by comparing with the results of experiment at the facility that is actually built in preparation for improving the shape of intake pipe in the future.

The results of numerical model simulation are shown in Table 2. Loss coefficient was 1.92.

Table 2. Loss coefficient at numerical model

	1/1 numerical model
Water density	997.0 kg/m^3
Water kinematic viscosity coefficient	8.572 E-7 m/s^2
Air molecular weight	29.0 kg/kmol
Air viscosity	1.772 E-5 Pa-s
Analysis program	CFD-ACE+

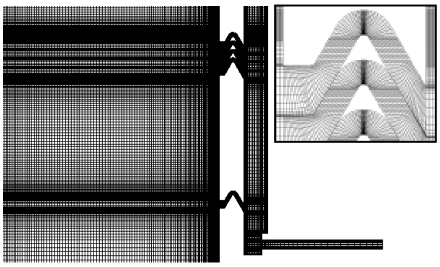

Figure 6. Mesh pattern of numerical model

Table 3. Loss coefficient at numerical model

Flow rate	8.0 m^3/s
Number of plates used	1
Intake pipe width	3.0m
Intake pipe height	0.70m
Flow speed	1.905 m/s
Difference in water level at water intake	0.354 m
Loss coefficient	1.92

Figure 7. Simulation of numerical model

3.3 Comparative Verification with Actual System Test

A test was conducted while water was running through the actual system. Loss coefficient calculated from difference in water level inside and outside the tower during the test conducted with running water came to 2.33.

Table 4. Loss coefficient at on-site test

Flow rate	7.1 m^3/s
Number of plates used	1
Intake pipe width	3.0m
Intake pipe height	0.70m
Flow speed	1.690 m/s
Difference in water level at water intake	0.34 m
Loss coefficient	2.33

Figure 8. Mesh pattern of numerical model

3.4 Summary of Loss Coefficient

The results of loss coefficient calculation from hydrologic accounting, hydrologic model experiment and numerical model analysis are summarized in Table 5. Loss coefficient obtained from hydrologic accounting was below the design value of 2.5 which is adequate. Loss coefficient from hydrologic accounting was smaller than that on the actual system test while loss coefficient from numerical model analysis was greater than that on the actual system test.

The deviation between the actual system and hydrologic model obtained here will be used for verification of the functions of large facilities in Chapter 4.s

Table 5. Summary of loss coefficient

	Loss coefficient	Difference with actual system test
Hydrologic accounting	2.17	+7.3%
Hydrologic model	3.04	+29.9%
Numerical model	1.90	-17.6%
Actual system test	2.34	-

4. APPLICATION IN LARGE INTAKE FACILITIES

4.1 Yubari Shuparo Dam

Yubari Shuparo Dam is a multipurpose dam under construction on Yubari River which is part of Ishikari River Water System in Hokkaido.

Table 6. ***Yubari Shuparo Dam Specifications***

Yubari Shuparo Dam Specifications	
Type	Gravity concrete dam
Location	Southern region of Yubari City, Hokkaido
Dam height	110.8 m
Crest length	390.0 m
Dam volume	Approx. 941,000 m^3
Water surface area	15.1 km^2
Total reservoir capacity	433,000,000 m^3
Maximum water utilization discharge	83 m^3/s

Figure 9. Mesh pattern of numerical model

4.2 Adoption of Free-Selective Air-Lock Intake System

As Yubari Shuparo Dam has large maximum water utilization discharge of 83 m^3/s, selective water intake facility that covers this singlehandedly will be the largest of its kind in the country.

The free-selective air-lock intake system has been adopted as a system superior in terms of economy and maintenance. Compared to other systems, however, it had inferior water intake performance from reservoir surface due to the depth of water intake required for securing the distance from intake pipe to water surface.

4.3 Improvement of Surface Water Intake Performance

The shape of intake pipe was improved to take water from locations closer to reservoir surface than conventional intake pipes. The shape of rim was moved upward to improve intake performance from the surface without changing the condition of water level difference. The results from verification of loss coefficient for the improved intake pipe are described below.

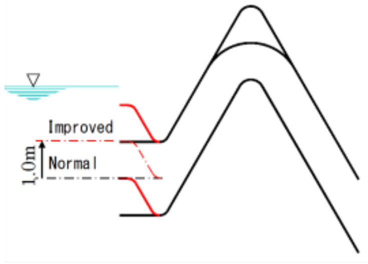

Figure 10. Conceptual diagram of improved intake pipe

4.4 Verification of Loss Coefficient Using Numerical Model

Loss coefficient of 2.5 was also selected in the design phase for Yubari Shuparo Dam as well.

In this study, loss coefficient for the improved intake pipe shape was verified by using a numerical model. As shown in Table 7, loss coefficient obtained from numerical model comes to 2.49 in view of the 17.6% deviation included in the numerical model formed in this study. Consequently, validity of design value 2.5 was verified. Conditions of analysis are same as those in Table 2.

Table 7. Loss coefficient of improved intake pipe

Water level difference at water intake according to numerical model	83m^3/s
Number of plates used	4
Intake pipe width	10.0m
Intake pipe height	0.75m
Velocity inside pipe	2.767m/s
Loss coefficient	2.05
Deviation of numerical model	17.6%
Loss coefficient considering deviation	2.49

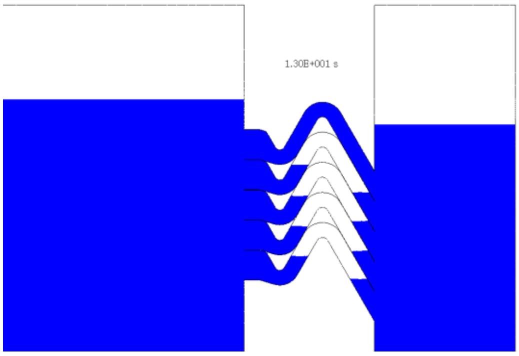

Figure 11. Simulation of numerical model

5. CONSTRUCTION IN YUBARI SHUPARO DAM

Lastly, the case of Yubari Shuparo Dam will be introduced to exemplify the construction of the free-selective air-lock intake system.

5.1 Fabrication

Intake pipe must have an integrated structure using welding connection and installed in order according to the placement process of dam body concrete. For this reason, intake pipe was not divided in the direction of span. Instead, it was divided into three parts in depth direction on each layer so that it will conform with shipping restrictions. In addition, welding and air-tightness test were performed repeatedly on each intake pipe parts to meet high air-tightness requirements, and pre-assembly identical to actual installation was performed to simplify replication on the site.

Air control unit was comprised of commercially available compressor, air-driven ball valve, vacuum pump and receiver tank among others. Air-driven ball valve and manual ball valve were combined and mounted on a frame to serve as an air control unit, and was transported to the site after a performance test and leakage inspection..

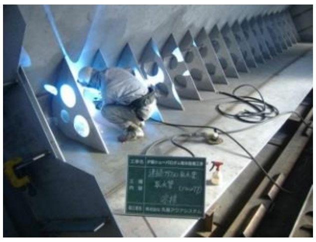

Figure 12. Intake Pipe Welding

Figure 13. Intake Pipe Airtightness Test

Figure 14. Intake Pipe Assembly

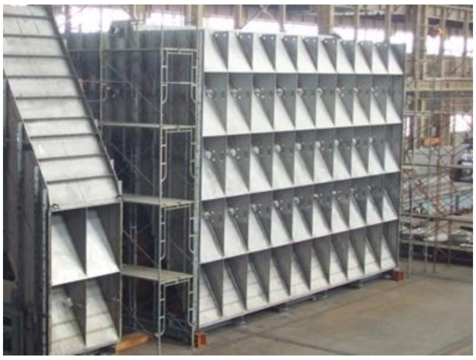

Figure 15. Intake Pipe Temporary Assembly

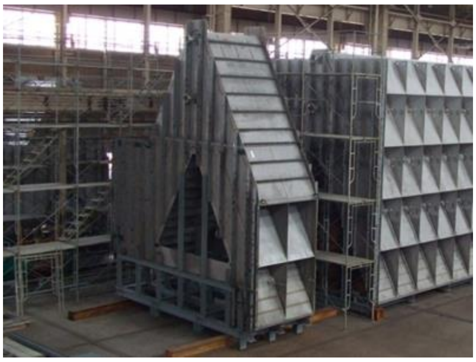

Figure 16. Bottom Intake Pipe Temporary Assembly

Figure 17. Air Control Unit

Figure 18. Air Control Unit Interior

5.2 Construction

As RCD method is used for placement of concrete for the dam body, each placement is performed over a period of approximately 7 days. For this reason, intake pipes were installed by setting up a temporary assembly base on the upstream area of the left bank in order to avoid impact on concrete placement. Intake pipes that were transported in segments were assembled and were lifted by 300t crawler crane to the top of the dam body for installation. Stages for temporary storage of materials were built successively around and above intake pipes that were lifted to the dam body. These stages were equipped with sliding scaffold, power generator, welding machine and compressor in order to perform the construction without placing the materials on the dam body concrete placement surface. As a result, it was possible to install intake pipes completely separate from concrete placement for dam body and the installation was ultimately completed prior to concrete placement.

Figure 19. Intake Pipe Installation

Figure 20. Intake Pipe In-situ Assembly

Figure 21. Intake Pipe Lowering In

Figure 22. Intake Lowering In

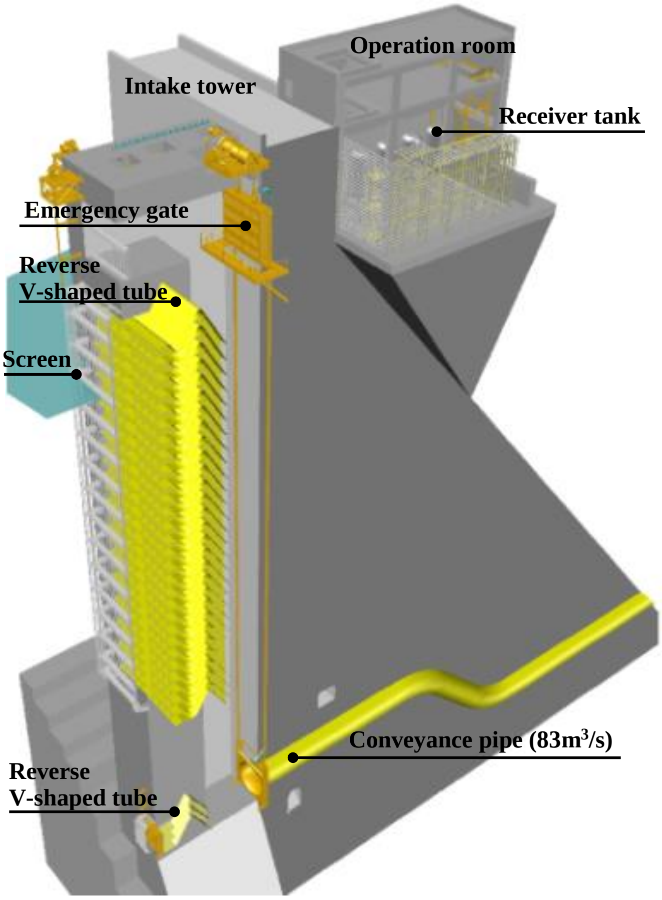

Figure 26. Outline Drawing of Yubari Shuparo Dam Intake Facilities

Figure 23. Air Pipe Installation

Figure 24. Receiver Tank Installation

Figure 25. Yubari Shuparo Dam Intake Facilities

6. CONCLUSION

Fundamental study was conducted on the free-selective air-lock intake system with regard to loss coefficient f on intake pipe which is a design parameter unique to this intake system. In addition, knowledge obtained from this study was used to verify the design adequacy of a larger system. Main conclusions are as follows.

1) This intake system, which is a new format of selective intake system, enables intake of water from any layer by filling and releasing air in reverse V-shaped intake pipe. For this reason, obtaining water level difference generated inside air-locked intake pipe through calculation is important in determining the shape of intake pipe.

2) As water level difference generated inside air-locked intake pipe will be equal to head loss of water passing through at intake pipe with flowing water, setting the correct loss coefficient f for intake pipe will be very important in designing this intake system. Confirming the adequacy of intake pipe loss coefficient f leads to establishment of intake pipe shape design method for various intake volume requirements.

3) Intake pipe loss coefficient f was obtained from water level difference measured between inside and outside the intake tower in hydrologic model, numerical model and actual system, and was compared with the results of hydrologic accounting. Deviation between the results of numerical model simulation and actual system was grasped as a result.

4) Comparative results of intake pipe loss coefficient f was used to compensate the results from numerical model simulation in order to verify the design adequacy of the free-selective air-lock intake system at Yubari Shuparo Dam.

5) This intake system has many materials that are buried into the dam body. At Yubari Shuparo Dam, however, assembly was performed prior to placement of concrete for the dam body by using sliding scaffold to carry out the construction without affecting the concrete placement.

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