Development and Operation of Free-Selective Air-Lock Intake in Shitsumi Dam

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ABSTRACT: The free-selective air-lock intake is a system to realize the gateless intake continuously and automatically by intake tubes and air-locks. This gateless intake system has been developed in 2000s in Japan, based on the air-valve intake which was originally invented in 1960s in England, and adopted in several earth dams in Malaysia since 1970s. Further, the multi-selective air-lock intake was developed in Haneji Dam in 1990s in Japan. The free-selective air-lock intake system was firstly adopted in Shitsumi Dam in Japan. The full operation of Shitsumi Dam since 2010 year proved the operation of this system was quite easy and the change of its intake position and quantity was very smooth with the high security of the structure. Eventually, its function and cost were found to be quite advantageous compared to conventional types. In this paper, authors describe the technological background and the latest operation of the free-selective air-lock intake through the first impounding of Shitsumi Dam.

1 OUTLINE AND TECHNOLOGICAL BACKGROUND

In Japan, the selective intake facility has become very common in dams which have been constructed since the 1990s, to cope with water quality issues such as eutrophication, coldness or turbidity. Nowadays, it is an indispensable facility for reservoir management. However, conventional selective intakes have had some problems, such as cost and operation of the facility, because of the use of heavy steel gates, winches and other machines.

The multi-selective air-lock intake system with semi-automatic operation was firstly applied at Haneji Dam in pursuit of the better management of reservoir water quality (Kawasaki et al. 2000, Kawasaki et al. 2001). Its major objective was to improve the operability and durability of intake facilities by using an electric air-lock, in which a suitable intake through reverse U-shaped intake tubes would be selected according to water level. Operation of this gateless intake facility started in 2002.

After the success at Haneji Dam, the free-selective air-lock intake was developed and installed to take in water at continuous water levels. This was greatly improved, so as to take in water more smoothly and to freely change the water intake volume. it was easier to operate and more economically efficient through a more advanced automatic operation using the latest electric technology. This new intake system was first adopted on the Shitsumi Dam.

The Shitsumi Dam profiles are shown in Table 1 and Figure 1. Though Shitsumi Dam is a middle scale flood control dam using free flow regulation, its notable feature is that the entire dam crest is a free flow spillway without any pier or bridge. Figures 2, 3 and 5 show its appearance, and Figure 4 and 6 show the free-selective air-lock intake.

Both the multi-telescopic-type cylinder gate with side walls and the free-selective air-lock type were considered to be suitable for the intake facility. The latter was actually adopted from the viewpoint of economy (in terms of the decrease of machinery, its gateless and maintenance-free structure) and aesthetic aspect, considering its unique dam crest shape.

The Shitsumi Dam was given an exceptional appearance by the use of free-selective air-lock intake which needs no facility above the dam crest. The impounding of Shitsumi Dam started in October 2009, and the full operation of the new intake system started in June 2010.

Table 1. Profiles of Shitsumi Dam.

Site: Iinan town, Shimane prefecture, Japan (located in the west of Honshu Island)	
Ownership and Administrator: Ministry of Land, Infrastructure, Transport and Tourism	
Purposes: Flood control, maintenance of normal river function, industry water and power generation	
Dam type: Concrete gravity dam	Flood control method: Free flow crest, 2 orifice
Construction period: April 2006 – March 2009	Completion of project: 2010 fiscal year
Height of dam body: 85.5 m	Length of dam body: 266 m
Volume of dam body: 416,000 m^3	Volume of reservoir: 50,600,000 m^3
Dam catchment area: 213.8 km^2	River: Kando river

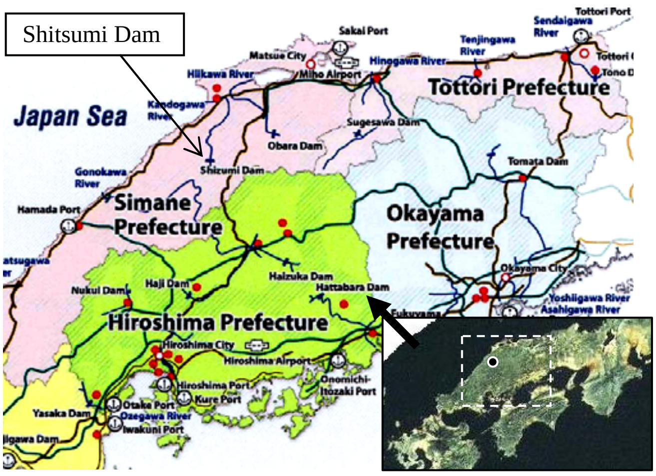


Figure 1. Location of Shitsumi Dam.

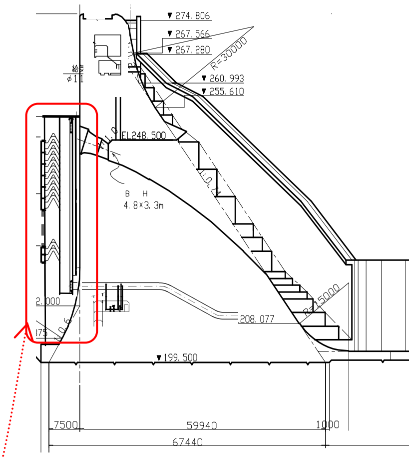


Figure 2. Cross section of the dam.

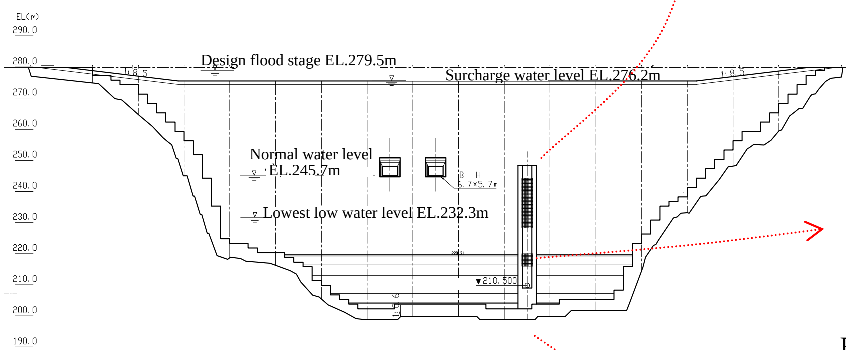


Figure 3. Upstream view of the dam.

Figure 4. Intake tower of Shitsumi Dam.

Figure 5. View from downstream.

Figure 6. View from upstream and intake tower.

2 AIR-LOCK MECHANISM AND FACILITY DESIGN IN SHITSUMI DAM

2.1 *Operating mechanism of free-selective air-lock*

With a conventional selective intake, water intake operation is conducted by moving the inlet to a specified water level. With a free-selective air-lock intake, water intake operation is conducted by locking or unlocking a water intake tube at a selected water level using compressed air. The air supply and release valves are normally air-locked. When the air supply valve is opened to feed compressed air to a water intake tube, the water flow is stopped. Conversely, water intake operation resumes by opening the air release valve to release compressed air in a water intake tube. Figure 7 illustrates the operating mechanism of an air-lock intake.

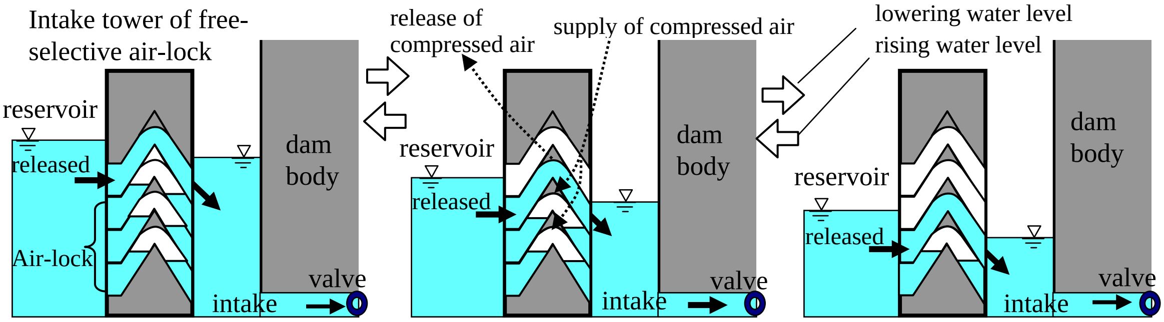


Figure 7. Smooth operation by changes of intake tubes according as the water level.

2.2 *Outline of free-selective air-lock intake in Shitsumi Dam*

Table 2 shows the specifications and dimensions of the free-selective air-lock intake facility on the Shitsumi Dam. The available intake range is narrower and the intake tubes are only eleven layers, because the normal water level is low.

Maintenance and rehabilitation of underwater equipment can be safely implemented by securing enough workspace (height: 1.4 m, width: 3.0 m) in the intake tubes underwater and virtually zero water velocity by using an emergency gate.

Table 2. Specifications and dimensions of the free-selective air-lock intake.

Available intake elevation	from EL.232.3 m to EL.245.7 m (Normal water level)
Intake Volume	normal intake: 1.7~8.0 m^3/s, emergency draw down: max 20.0 m^3/s
Number of intake tube	normal intake: 11 layers, bottom intake for emergency: 2 layers
Tube inlet (inside size)	width: 3.0m, height: 1.4 m

2.3 *Configuration of free-selective air-lock intake*

A free-selective air-lock intake consists of several sequentially positioned reverse V-shaped intake tubes, compressed air supply equipment, screen, water level sensor and control centre. It does not have a hoist and some other equipment included in conventional selective types. Because of this, it is possible to locate the machinery room in a gallery inside the dam body.

The control boxes, receiver tanks, compressors, air supply and release pipes, valves, and others are set together in a compact space for their easy maintenance. Table 3 shows the equipment and functions of the free-selective air-lock intake. The configuration is quite simple and the operation is silent because the number of power machines is very few.

Table 3. Equipments and functions of the free-selective air-lock intake.

Equipment item	Component	Function
Intake tube	Reverse V-shaped stainless steel tubes	To form or release air-locks for the water stop at the crown of the intake tubes
Air supply equipment	Compressor, supply and release pipes, valves, receiver tank, vacuum pump	To stop or allow intake water by air supply or release operation

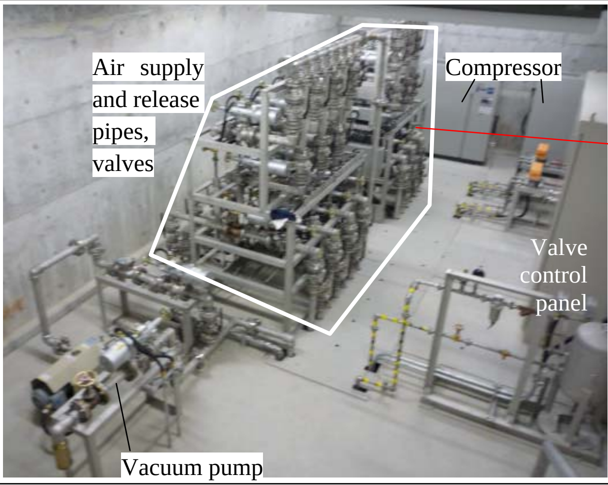
Screen	Stainless steel bar	To prevent trash and driftwood flowing in
Water level sensor	Pressure gauge (inside of tubes)	To detect the air-lock condition by water levels/heads in and around tubes
Control box	Control panel (including computer system, device box, indicators)	To control air valves or outlet gates To start a compressor or a vacuum pump

Though the air-lock itself has an automatic release mechanism for an excessive water head, some fail-safe countermeasures are also installed such as double air supply and release pipes, double measurement devices, and an emergency gate in the intake tower. At the same time, more durable materials such as stainless steel are adopted underwater.

Figure 8, 9 and 10 show receiver tanks, indicator panels and a valve control room. Figure 11 shows a perspective of the whole system. The water is firstly taken in through the released intake tubes at a requested elevation and layer, and flows down through the conveyance pipe, then appropriate volume of water is discharged at the valve house according to the valve operation.

Figure 8. On-site operation room.

Figure 9. Indicator panel of air-lock and water intake situation.



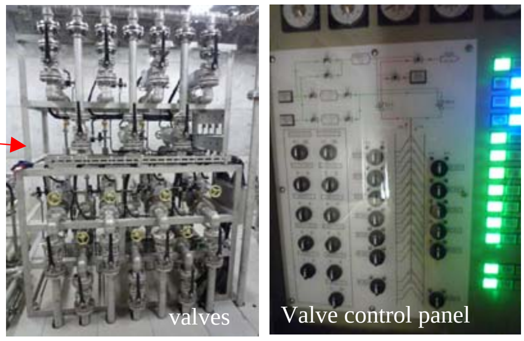


Figure 10. Valve control room:
Air supply and release pipes, valves,
2 compressors (packaged screw type unit), 1 vacuum pump, and other air equipments.

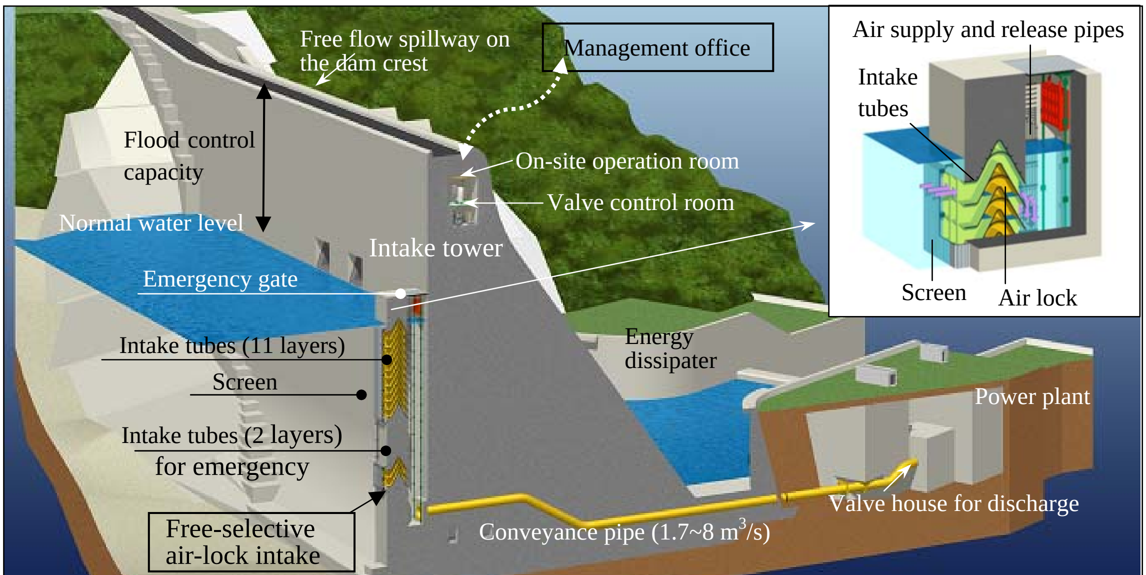


Figure 11. Perspective of the whole intake system in Shitsumi Dam.

3 MANUFACTURE AND INSTALLATION OF INTAKE TUBES

The intake tube unit (see Figure 12) was split into several parts after a temporary assembly test at the factory. They were transported to the dam-site, and assembled again by welding.

The assembly and installation of the intake tube unit took about 18 days, and the installation took about 12 days per unit with five lifts by the tower crane. The items below are key points in the installation of intake tubes (Nakagawa 2010).

1) Since installation of intake tubes needed to use a tower crane (13.5 t × 75 m) on the right bank, the dam concrete lift schedule was influenced. So, to reduce the crane cycle time, the assembly yard was located within the operating radius of the tower crane (see Figure 14 and 15), and intake tube units were assembled in advance (two or three tubes per unit).

2) The installation of the intake tubes was scheduled to take place sequentially according to the dam concrete lift schedule, because the dam concrete placement needed to be stopped during the installation of the intake tubes.

3) The intake tube is required to be highly air-tight. Thus, the most desirable structural joints were arranged to minimize the welding where air-tightness was necessary..

4) Since the work space in the intake tower around the intake tubes was very narrow, enough concrete working space was difficult to secure. Therefore, the temporary platforms around the intake tubes were provided for the concrete placing and compaction work.

5) In the areas where air supply and release pipes were densely set, it was difficult to pour concrete by a bucket. In these areas, concrete placement was implemented using a pump, and concrete was transported to the pump hopper by a bucket of the tower crane.

6) The cavity space under the lowest intake tube (see Figure 13) was filled with high flow-concrete. On the other hand, the cavity on the crown of every intake tube was grouted by cement milk after the concrete placement.

Figure 12. Temporary assembly test of all atainless intake tubes at the manufacturing factory.

Figure 13. Installation situation of the lowest intake tube.

Figure 14. Intake tube assembly yard located within the operating radius of a tower crane.

Figure 15. Assembly of an intake tube unit in the assembly yard.

4 OPERATION TEST OF FREE-SELECTIVE AIR-LOCK INTAKE

The first impounding of Shitsumi Dam started in October 2009, and two operating tests were implemented to confirm the performance such as flow, air pressures inside the intake tubes under different water levels and intake volumes (Nakagawa 2010).

After these operating tests, the full operation was started in June 2010.

4.1 *First operation test of the free-selective air-lock intake*

The first operation test was implemented in December 2009 to check mainly underwater velocities in front of the screen by dropping a velocity meter as shown in Figure 16. The velocities were measured at 0.2 m depth intervals under the conditions in Table 4.

Figure 17 shows the measured intake velocities where the number of the intake tubes is one or two at different elevations. It was found that:

1) As a whole, the maximum intake velocities occurred around the inlets of released tubes, however these velocities were small under 8 cm/s because the intake volume (max.1.1 m^3/s) was small. Further, it became clear that these air-locked tubes successfully stopped the water, because there were near zero velocities around the inlets of air-locked tubes.

2) Pattern 1 (All intake tubes were air-locked, and No.8 intake tube was open): The velocity in front of the open intake tube (indicated as "★" in Figure 17) was found to rapidly decrease from 8 cm/s to 6 cm/s. This decrease was influenced by the girder of the screen bar.

After No.8 intake tube was opened, its air pressure decreased to 7.8 kPa from 21 kPa. As this value of No.8 was equal to the calculated value (7.82 kPa), it was confirmed that air-locking and unlocking were satisfactory and the operation was successful.

3) Pattern 2 (No.8 and 11 intake tubes were opened, and No.9, 10, 12 and 13 were air-locked): The maximum intake velocities occurred around the inlets of opened No.8 and 11 tubes at about 8 cm/s. Further, after No.9 intake tube was air-locked, its air pressure increased to 32.9 kPa from 18.7 kPa. As this value of No.9 was equal to the calculated value (32.46 kPa), it was confirmed that air-locking and unlocking were satisfactory and the operation was successful.

Table 4. Condition of the operation test.

Item	First operation test in Dec.2009	Second operation test in Jun.2010
Reservoir water level	EL.236.49 m → EL.236.99 m	EL.246.52 m → EL.244.10 m
Intake volume	Max. 1.1 m^3/s	6.8 ~ 7.2 m^3/s
Gauging pitch of depth	Velocities by 0.2 m pitch of depth at the inlet of intake tubes	
Patterns of the test	Air-lock and unlock, total 10 cases	5 patterns, total 18 cases

4.2 *Second operation test of the free-selective air-lock intake*

The second operating test was implemented in June 2010 to check the vertical distribution of intake velocities and other items at the maximum discharge volume, which was about 7 m^3/s.

Figure 18 shows the intake velocities at 0.2 m depth intervals, while changing the number of intake tubes at different elevations. It was found that:

1) The maximum velocities occurred around the front of opened tubes as in the first operating test. These velocities were about 40 cm/s in pattern A, 17 cm/s in pattern B and 9 cm/s in pattern C, and intake velocities for deep water tended to be bigger than those in shallow water.

2) Though various operations changing the number of intake tubes and their elevations were performed, these were carried out smoothly and safely.

3) The water temperature in front of the screen was about 18 degrees for the surface water, and it was 10 degrees at depth. If the temperature gradient is measured in advance, it is easy to control the discharge water temperature by mixing water from the released intake tubes at different elevations.

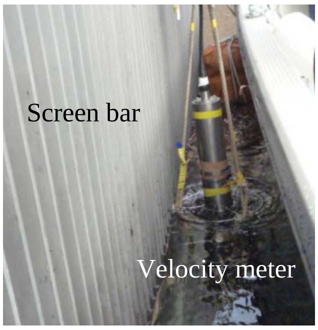
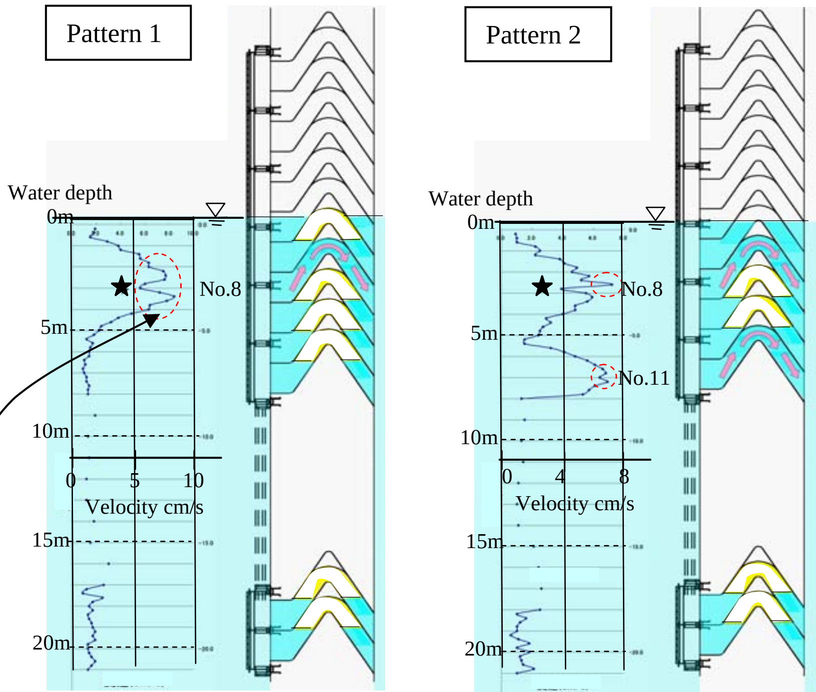


Figure 16. Measurement by the velocity meter

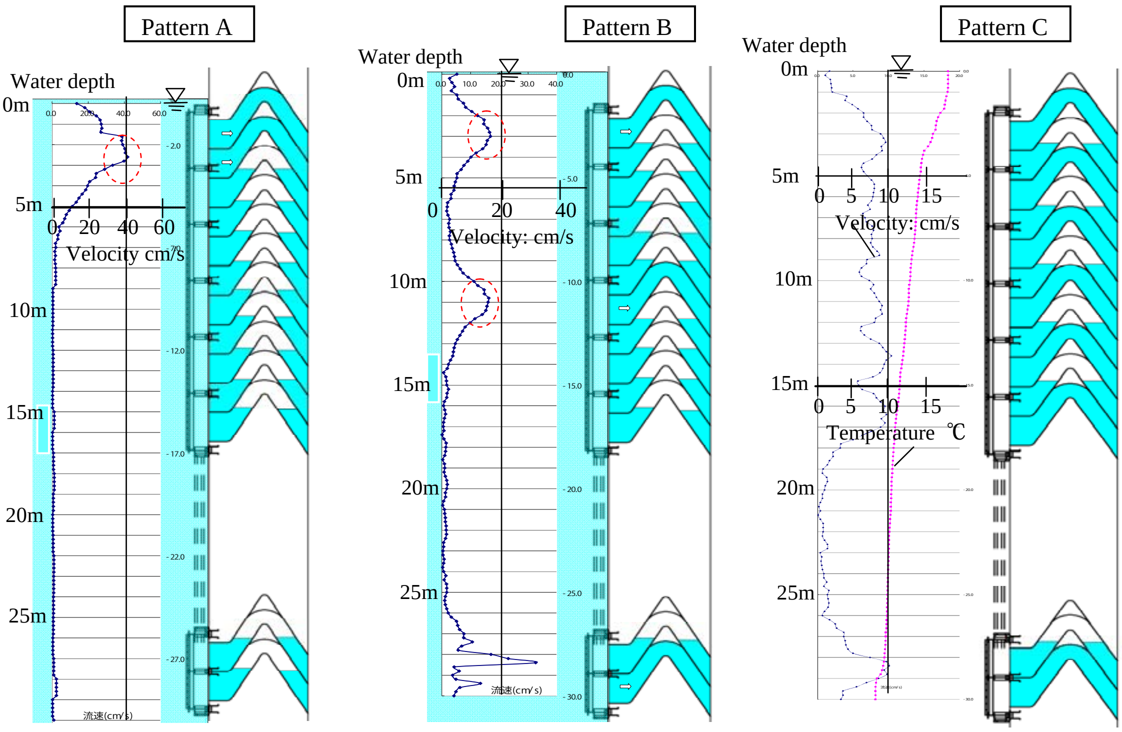
The maximum velocity area occurred at the inlet of released tubes (red circled) (★ was disturbed by the girder of the screen)



Released tube: No.8 (layer)
Reservoir water level: 236.86 m

Released tube: No.8 &11
Reservoir water level: 236.66 m

Figure 17. Vertical distribution of the velocity in front of the screen in the first operation test.



Released tube: No.1,2 (layer)
Reservoir water level: 245.30 m
Qout: 7.09 m^3/s, Δh:33 cm

Released tube: No.1,7,13
Reservoir water level: 246.49 m
Qout: 7.24m^3/s, Δh:12 cm

Released tube: No.1,3,5,7,9,11,13,
Reservoir water level: 246.46m,
Qout: 7.14 m^3/s, Δh:8 cm

Figure 18. Vertical distribution of the velocity in front of the screen in the second operation test (Qout: the discharge flow, Δh: the water level difference between inside and outside of the intake tower).

5 CONCLUSIONS

The free-selective air-lock intake has just started its operation in 2010 at Shitsumi Dam, and it has already demonstrated successful results such as the easier and safer operation, lower cost and compact installation. The key findings were as follows;

1) The well-controlled air-lock mechanism was achieved by using the free-selective air-lock intake system, which is mainly composed of accumulated reverse V-shaped intake tubes and air supply and release pipes, without any gates, machinery or structure on the dam crest.

At the same time, this system enabled more simplified automation because the air locks can be automatically activated and released.

2) The system was greatly advanced by simplifying the machinery and structures and adopting the latest electric measurement systems, at the same time strengthening fail-safe and durability countermeasures such as double laying air supply and release pipes, stainless intake tubes, and so on.

Further, the maintenance and rehabilitation of underwater equipment can be safely implemented with enough workspace (height: 1.4 m, width: 3.0 m) in the intake tubes and very low water velocity.

3) It is important to plan the installation work of the free-selective air-lock intake so as not to obstruct the concrete work of the dam body. Various effective construction measures were used at Shitsumi Dam.

4) The result of operating tests proves that this system has satisfactory performance in terms of function, safety, operability and cost. In particular the intake method is notably flexible depending on changes in the water level and the intake elevation. Thus, this intake system has a wide ranging capacity from small to large volumes by increasing the number of intake tubes.

5) Recently in Japan, this intake system is rapidly being installed in many dams such as Obara Dam (Shimane pref.), Yunishigawa Dam (Tochigi pref.), Yubari-Shuparo Dam (Hokkaido pref.), Tono Dam (Tottori pref.), Upper-Kurokuigawa Dam & Hirase Dam (Yamaguchi pref.), and so on. The intake capacities for normal use without floods vary from approximately 0.5 m^3/s to 80 m^3/s.

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