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Development of a Selective Water Intake Facility with Bellows

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ABSTRACT:
The Report on the selective water intake facility with “bellows,” which was adopted by Taiho dam. The facility features high water tightness, light weight and bellows that can be stretched widely.

Keywords: Selective Water Intake Facility, Bellows, Cost Reduction

1. BACKGROUND OF DEVELOPMENT

A water intake facility of dam must have ability to intake water efficiently and continuously from a wider range of any level of the reservoir, and must have highly water-tightness for using high quality water.

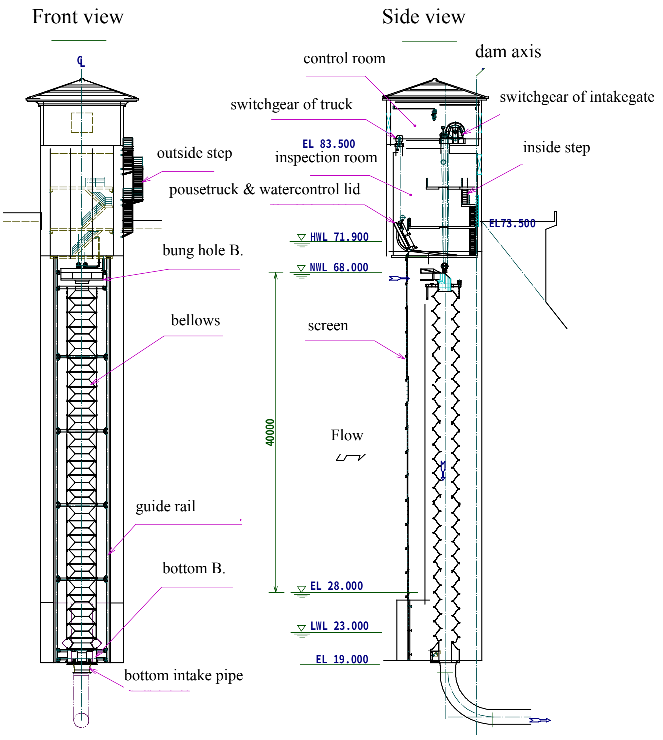


Figure 1. Selective water intake facility with bellows

For this reason, in recent years, round multi-stage intake facilities stretching several multiple circular steel pipes telescopic-like have been successful and most often used. However, including the life-cycle costs, the technology to reduce more costs is required. So, we have developed a selective water intake facility with “bellows” that is more highly water-tight, more lightweight and can be stretched more widely. And in Taiho dam located in northern Okinawa Island, we adopt it.

2. OUTLINE OF TECHNOLOGY

2.1. Selective Water Intake Facility with Bellows

(Figure 1) shows the selective water intake facility with bellows used in Taiho Dam. It is a wall-installation type water intake facility, which is installed in the upstream of the dam site and is used to intake water from dam reservoirs. The gate is composed of a bung hole block, bellows and a bottom block, from top to bottom. The water that enters the bung block is led to the water intake pipe at the bottom via the bellows and the bottom block and is distributed to the downstream of the dam.
The bung hole block is moved up and down by the switch gear in the control room, making it possible to intake water from any arbitrary depth. During this operation, the bellows extend or contract to follow the movement of the bung hole block. The bung hole block, the bellows and the bottom block are guided properly to the guide rails on both sides of the gate by the guide roller.
The inspection room is located below the control room, and it is possible to pull up the entire water intake gate and inspect it on the stable platform.
(Figure 2) shows the bung hole block photographed from the inspection room, which is above the bung hole block. The bung hole is widely open toward the screen on the upstream side so as to intake water effectively.

Figure 2. Bung hole block

(Figure 3) was photographed from the upstream side of the bottom block, looking up the extended bellows. The bellows, which extend responding to elevation of the bung hole block, are suspended sequentially by the hanging belts mounted on 6 outer portions of the bellows. The whole bellows used in Taiho Dam feature a vertical elasticity of 40 m, with 3.285 m under contacted condition and 43.285 m under extended condition.

Figure 3. Extended bellows

2.2. Structure of Bellows

The bellows are composed of rubberized fabric sheets and rings made of stainless steel. They can be folded at an angle of about 45 degrees, resulting in light weight and high elasticity. (Figure 4) shows extended and folded bellows. The bellows used in Taiho Dam feature a total extension height of 1.8m per section, which is 1.5 m in inner diameter and 3.3 m in outer diameter. The height of extended bellows is controlled at 1.8 m by the hanging belts, which are mounted around the bellows to support them.

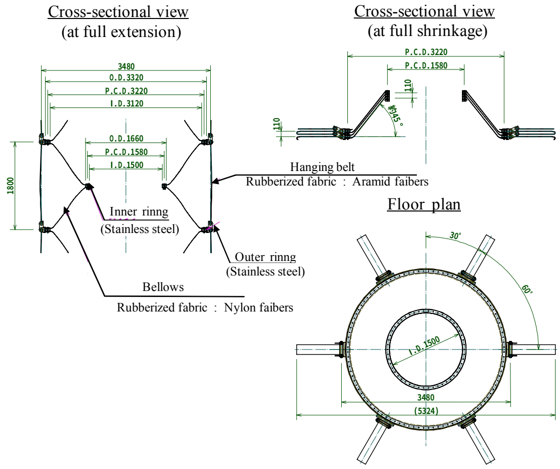


Figure 4. Extended and folded bellows

3. PROCESS OF THE DEVELOPMENT

3.1. Proposal of New Technologies

In respect to the selective water intake equipment for the Taiho Dam, we invited proposals of new technologies that are free from traditional approaches in FY 2003. Proposals for structures and detailed technologies of small-scale selective water intake equipment were invited. The conditions are as follows.

[Conditions for proposed technologies]
Range of technologies: New technologies that contribute to cost reduction, including reduction of the life cycle cost.
Applicable equipment: Selective water intake equipment installed on the body of concrete gravity dam.
Functions of the equipment:

(1) Water intake is possible at any arbitrary level between the full level and the minimum level of water, where the difference of elevation is 45m, so as to maintain quality of influent and standing water

(2) Maximum water intake amount to be 2.2m3/s

(3) Smooth maintenance is allowed even if the reservoir level remains full

(4) The altitude of discharge conduits in the downstream is approximately EL15.5m, and the discharge equipment for lowering the maximum water level discharges water at a rate of 26.6m3/s

(5) After water intake, the water is distributed for generation of power for management and for direct water supply via pressure lines.

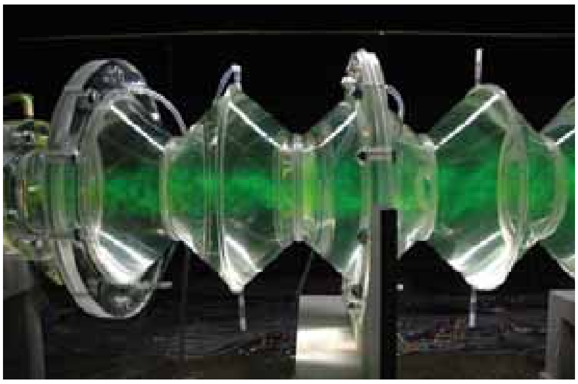
We received applications form 10 companies and the selective water intake facility with bellows was adopted evaluating the compatibility to design conditions, feasibility, contribution to cost reduction, etc.

3.2. Test for Confirmation of Applicability

Tests were performed on materials and structures of the selective water intake facility with bellows and its water management, with a focus on bellows, in 2004 to examine applicability of the facility. The outline is as follows.

3.2.1. Rigid model test

We conducted a flow test using a rigid model simulated to the bellows shape to examine the flow regime, pressure fluctuation property and loss property. The scene of the test is shown in (Fig. 5). Based on the results of loss property measurement and upon consideration for the conditions of Taiho Dam, we reached a conclusion that the inner diameter of the inner rings of the bellows should be 1.5 m. It was confirmed that the head loss is estimated at 2.6 m if the inner diameter of the inner rings is set at 1.2 m, leading to an increase in the tension inside the bellows and a reduction in the safety of the facility.



Picture 5. Rigid model test

3.2.2. Flexible model test

On the basis of the results of the rigid model test, vibration and deformation of the flexible bellows were examined using a flexible model. The scene of the test is shown in (Fig. 6) The test proved that the vertical vibration of the inner rings is caused by the water flow force. We judged, however, that it is unlikely that fluctuations in flow amount caused by the vibration affect the control of power generated for operation.

Figure 6. Flexible model test

3.2.3. Measurement test for mechanical properties of the rubberized fabric

The rubberized fabric sheets used in the bellows are made by coating strong nylon fabrics with rubber and are vulcanized into a conical shape. Through the rigid model test and the flexible model test, it was anticipated that the sheets will be subjected to repeated application of load due to pressure difference caused by the head loss as well as vibration and pressure fluctuation caused by the flow force. To confirm the durability of the sheets, we performed a water pressure resistance test and a bending fatigue test to evaluate the strength. For evaluation of the strength of the specimen, the reliability was ensured by utilizing the technologies based on the "Guideline for rubber tube weir technologies (draft)," a standard on rubber weir tubes consisting mainly of rubberized fabric sheets.

The hanging belts are also made of rubberized fabric sheets because they also need to be flexible. The structure at the ends of the belts was evaluated by preparing a specimen and conducting a static strength test using the specimen. We decided to use aramid fibers, which are superior to nylon fibers in strength, because the belts are subjected to heavy loads.

3.2.4. Operation test using a 1/3model

A model sized 1/3 of the actual unit and consisting of three sections was used to examine operating conditions in air and water.

Through the test, important information for designing layout of bellows that are stored in convex shape.

It was discovered that the bellows swell inward due to the external pressure caused by the difference between the inner and outer water levels, making it difficult to fold them into a concaved shape, when the bellows are designed to be stored in a concaved shape.

3.2.5. Operation test using a 1/1model

To examine the behavior of bellows membranes more precisely, an underwater test was performed in 2007 using 3 sections of actual size bellows (Figs. 7 and 8). Through this test, we confirmed that the bellows can be stored without any troubles even if there is a difference between the inner and outer water levels. We also found that the shrinkage of the bellows due to difference between the inner and outer water levels as well as the weight of the outer rings play important roles in shrinkage of the bellows.

Figure 7. Operation test in underwater

Figure 8. Operation test in underwater

3.3. Designing for Introduction to Taiho Dam

Designing of the facility for introduction to Taiho Dam was started in 2005, utilizing the knowledge and basic data obtained through the tests. In addition to the main body of the bellows, civil engineering structures, bellows supporting structures (guide rails), bung hole, bottom block equipped with a security gate, water control cover, screen, etc. were also planned and designed.
In respect to the structure for supporting the bellows, a guide roller was mounted in every 5 sections, reflecting the results of vibration analysis. Each of the functions was also reviewed before working out the major specifications indicated below.

[Specifications for the selective water intake facility with bellows intended for Taiho Dam]
Model Bellows-type water intake gate mounted on side wall
Maximum water intake volume2.222 m3/s
Range of selective water intakeNWL. 68.0 - WL. 28.0 (40 m)
Size of bellows Φ1.500m/Φ3.300m x 24 sections + 1 spare section

3.4. Installation work at Taiho Dam and Operating Condition

The installation was started in 2007 and completed in March 2009. The installation was performed carefully by confirming the characteristics of the facility in stages including detailed designing, manufacturing and installation.
Troubles indicated in 3.4.1 and 3.4.2 were observed in the test operation during the test filling. However, the causes were identified and measures were discussed to make effective improvements. As a result, the bellows type water intake facility has been delivering intended performance and has been operated to intake water. The safety has been conformed through a long-period operation with the maximum intake volume (2.222 m3/s)

3.4.1. Improvement of guide rings
During the test operation with water, deformation was observed in arms of guide rings that support the guide rollers. Upon analysis, we estimated that the troubles were caused by the force of flow applied on the bellows at the guide rings. As countermeasures, the bellows connection at the guide ring was improved and the arms were reinforced. (Figure.9) Shows the deformation in the arm of the guide ring and a cross-sectional view of the reinforced arm.

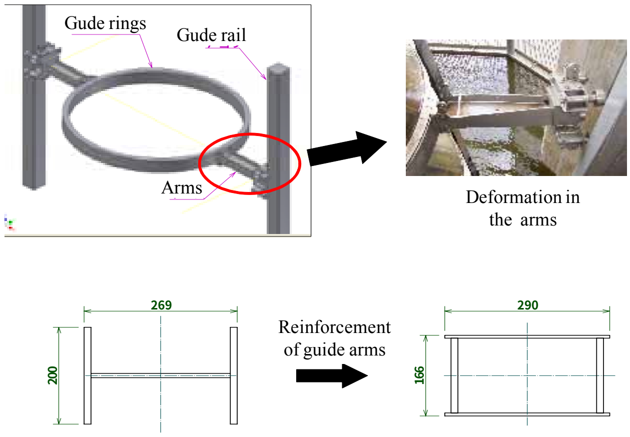


Figure 9. Information in the arm of the guide ring and a cross-sectional view of the reinforced arm.

3.4.2. Correction of defective storage of hanging belts
A trouble was also detected in storage of the hanging belts that suspend the bellows. The links connected to the belts were not turned for storage, which could prevent proper stacking of the bellows. We analyzed the process of folding the hanging belts and created a restraining hardware to solve the problem (Figure 10).

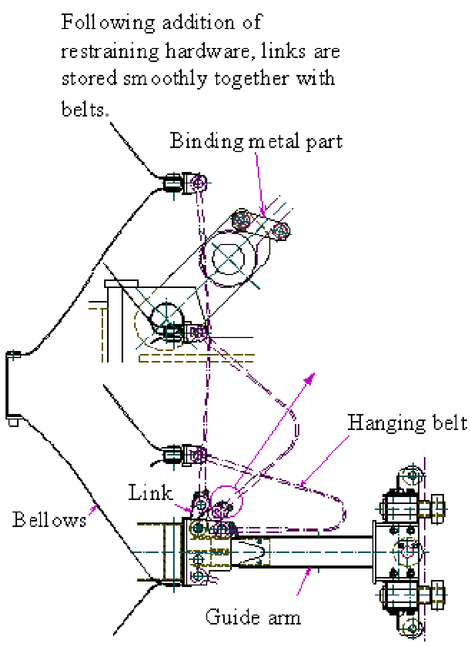


Figure 10. Figure showing movement of hanging belt and rink.

4. EFFECTS OF THE DEVELOPMENT

The effects of the selective water intake facility with bellows that has been developed are explained below.

1) cost reduction (down about 40% , including this life-cycle cost) (SeeTable-1)
2) load relief to raise and lower facility because of large amount of stretch and light weight
3) ease to adopt such as redevelopment projects because of reduction of installation costs

Table 1. Comparison of economic efficiency

Comparison of economic efficiency / Compared case	wall-mount multilayer circular type	Bellows type
Construction	100%	56%
Maintenance cost (30 years)	100%	50%
Total	100%	54%

5. CONCLUSION

Functions and performances required of water intake facilities vary depending on the dam, and validity of the introduction needs to be examined at each site before selection of a bellows-type water intake facility. The selective water intake facilities with bellows are economical and feature high elasticity, while they are being downsized. A positive economic impact is expected from introduction of the facilities to many dams.

They can also be used by the redevelopment projects of existing dams and for renewal of water intake equipment. In redevelopment projects, functions of the new facilities are usually expected to be superior to those of existing facilities. In addition, the working environment is generally severe for installation on existing dams, resulting in high installation cost in many cases. The selective water intake facility with bellows is light, requires less installation cost, features high water tightness and elasticity and provides high performance in low cost.

REFERENCE

STANDARD ON RUBBER TUBE WEIR TECHNOLOGIES (DRAFT)
Japan Institute of Construction Engineering/, Sankaido in Japanese.