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Design and Construction of the Discharge Facilities of the Shitsumi Dam

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ABSTRACT：
The Shitsumi Dam is a gravity dam intended to control flooding by flood control system without gate operation. New technologies were introduced in its design, including a "All over the dam crest" emergency spillway and a "free-selective airlock intake" water utilization facility. This simplified the dam crest and achieved an economical dam body design offering superior landscaping and construction period. Construction of the crest, deflectors, and training wall at the toe of the dam body incorporated a number of innovations to ensure reliable functionality during overflow and to ensure efficient work execution.

Keywords: *gravity dam, flood control system without gate operation, all over the dam crest, free-selective airlock intake*

1. SHITSUMI DAM PROJECT

The Shitsumi Dam is a concrete gravity dam using the flood control system without gate operation (Table.1 Fig.1～5).

In the Shitsumi Dam Project the local government purchased a mountain forest from the dam site to upstream area of 5 km. This action eliminated the need to build forest maintenance roads and thus enabled the free flow crest system to be used.

Table 1. Profile of Shitsumi Dam

Item	Contents
Site	Iinan town, Shimane Prefecture, Japan
Dam catchment area	213.8 km^2
Ownership and Administrator	Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Purposes	Flood control, maintenance of normal river function, industry water supply and power generation
Dam type	Concrete gravity dam
Project period	1986–2010 (fiscal years)
Dam Height	81 m
Crest Length	266 m
Volume of dam body	416,000 m^3
Volume of reservoir	50,600,000 m^3
Flood control system	Free flow crest, 2 orifice

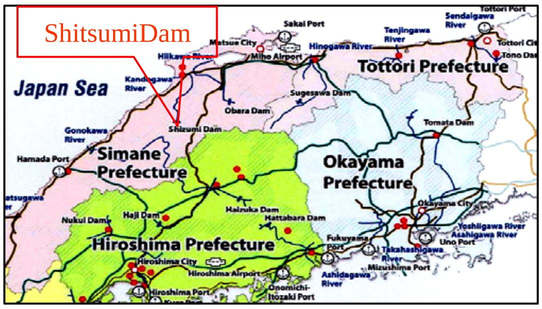

Figure 1. Location of Shitsumi Dam


Figure 2. Downstream view of the dam


Figure 3. Downstream view of the dam (during overflow)

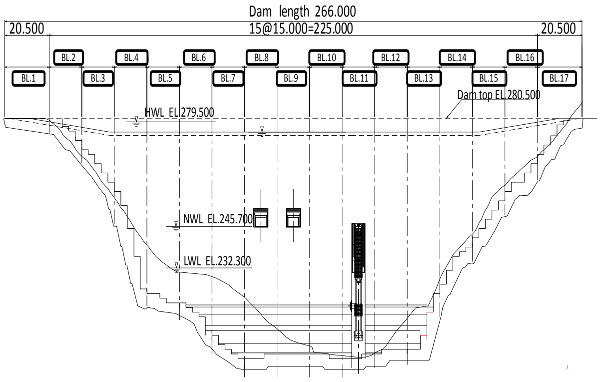

Figure 4. Upstream face of the dam

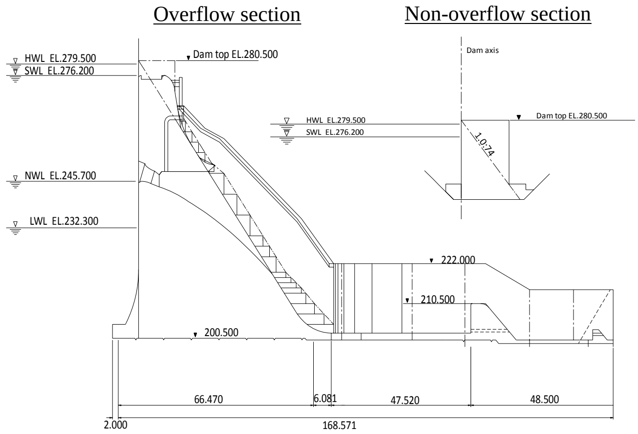

Figure 5. Typical section of the dam

2. SHAPE OF THE SHITSUMI DAM BODY

2.1. Characteristics of the Discharge Facilities

The discharge facilities of the Shitsumi Dam consist of the spillway, emergency spillway and free-selective airlock intake. The two major features are as follows:

①The emergency spillway is a ”All over the dam crest spillway”, and therefore has no crest bridge. The dam crest is designed to serve as the free overflow spillway and the service road for inspection and maintenance of dam body (Fig.6,7).

Figure 6. Dam crest (normal)

Figure 7. Crest (overflow)

This means that there is no need to cross the dam crest, which therefore allowed the crest road to serve only as a service road for maintenance.

An inspection gallery was constructed on the upper part (EL 266 m) for visual inspection of the right bank area during overflow and is also used to cross to the right bank.

②The water utilization facility uses a free-selective airlock intake for the first time in Japan. The dam crest was constructed with no protruding structures such as a gate operation room (Fig.8～10).

The free-selective airlock intake system opens and closes the gate by pneumatic control of continuously arranged inverted V-shaped pipes of the same shape. The operation facility consists of pneumatic control units including compressors, and the machine room is installed in the inspection gallery by expanding the gallery space. The dam body also contains the machine room for the internal elevator. These innovations successfully eliminated the need for facilities on the dam crest while maintaining normal functionality.

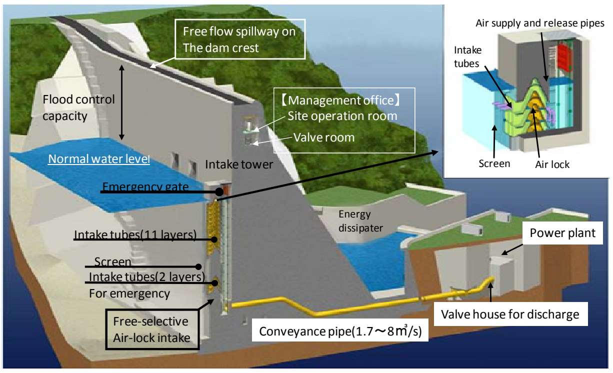

Figure 8. Perspective of the intake system

Figure 9.
Onsite operation chamber

Figure 10.
Valve control chamber

2.2. Flood Discharge Facility Design

The flood discharge design of the Shitsumi Dam is shown in Table 2. This design is intended to control the design flood discharge based on the total amount of flood discharged from the emergency spillway and the regulating spillway at the time of the design flood water level.

The structural details of the dam crest and other major parts of the dam structure were determined by hydraulic model experiments. These experiments required the ability to create a stable flow of water and to provide the necessary functions.

Table 2. Flood discharge design of Shitsumi Dam

Item	Amount
Design discharge	500 m^3/s
Design maximum discharge	680 m^3/s
Design high water discharge	1,400 m^3/s
Design flood discharge	2,680 m^3/s
Low water level	EL 232.3 m
Normal water level	EL 245.7 m
Surcharge water level	EL 276.2 m
Design flood level	EL 279.5 m

2.2.1. Emergency spillway

The Shitsumi Dam is partitioned into 17 blocks (15 m wide each). The dam crest located from Block.4 to Block.14 is a free overflow crest designed to serve as an emergency spillway. The elevation of the free overflow crest is the surcharge water level, and the overflow depth is 3.3 m and the overflow length is 199 m. The downstream side overflow crest is the section that determines the amount of overflow, and the overflow shape was determined from the hydraulic model experiment. The crest width was set to 12.33 m so as to satisfy the conditions of the service road.

The section between the overflow part and the non-overflow part on both banks is sloped at a gradient of 11.8% so as to use the crest as a service road. The regulation for a road with small traffic volume (longitudinal gradient of not more than 12%) was applied to determine this gradient. The elevation of the service road was lowered by 1.1 m from that of the overflow crest. This is because when the upstream and downstream overflow crests are regarded as the parapet of the road, the standard for bridge protection fence height must eventually be applied. The width of the service road was set to 7 m to allow access by truck cranes and other large vehicles.

Those vehicles were necessary for the installation and removal of closure gates at the regular spillway during initial impoundment, inspection and maintenance of the dam body or service operations on the right bank slopes.

The detailed shape of the crest is shown in Fig. 11, and a photo showing the work of installation and removal of gates for initial impoundment on the dam top is seen in Fig. 12.

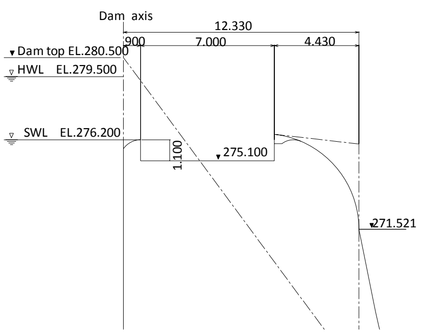

Figure 11. Configuration of dam crest

Figure 12.
Installation of closure gate for flood control test

2.2.2. Regulating spillway

The regulating spillway is equipped with two outlet pipes (bell-mouth orifice of 4.8 m in breadth and 3.3 m in height) with the normal top water level set to the height of the inlet.

The outlet of the spillway on the downstream side of the dam body is covered by the overflowing water when water is discharged from the emergency spillway. To divide the water flow from the emergency spillway, a deflector and the outlet of the air supply pipe are placed on the arc part of the downstream side of the overflow crest (Fig.13). A deflector was also installed at the outlet of the regular spillway. This stabilizes the discharge from the spillway.

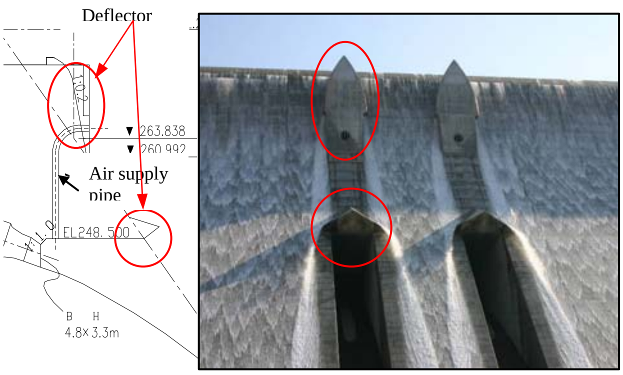

Figure 13. Division of water flow at the outlets pipes

2.2.3. Training wall

Water overflowing the crest is directed to the energy dissipator by the training wall (Fig.14). A chute block and an overhang-type deflector were installed to control the overflow and reduce the height of the training wall.

As the protrusion of the deflector is 1.5 m, it was expected to be very difficult to install. Nevertheless, this structure was selected for economic and aesthetic advantages, which included a reduction of about 5 m in the height of the training wall, which may go up to 20 m.

Figure 14. Training wall

2.2.4. Energy dissipator

The flow rates used in designing the values for each element of the energy dissipator are shown in Table 3.

Table 3. Flow rates for energy dissipator design

Element	Primary energy dissipator	Secondary energy dissipator
Apron length	Design flow for energy dissipator 1,400 m^3/s	Design maximum discharge 680 m^3/s
End sill height		
Training wall height	Design flood discharge 2,680 m^3/s	

The energy dissipator that has a training wall receives water through the side from the emergency spillway. The design flow for the primary energy dissipator is determined as the total front overflow discharge at the design flood level (EL 279.5 m) and the discharge from the regulating spillway (1,400 m^3/s).

The width of the energy dissipator was set to 40 m by considering the condition of the downstream river channel. The planar shape of the energy dissipator is bent by about 25° toward the left bank relative to the downstream direction of the spillway. Therefore, the front overflow discharge from the emergency spillway was calculated based on the front flow width of 60 m while considering the shape of the training wall.

The hydraulic model experiment revealed a phenomenon in which planar eddy currents formed inside the primary energy dissipator as a result of an increase in discharge from the regulating spillway and ran down without dissipation. This is because the energy dissipator has a bent planar shape. As a solution, a block (5×2.5 m) was placed on the right side wall of the primary dissipator to mitigate the formation of the planar eddy (Fig.15,16).

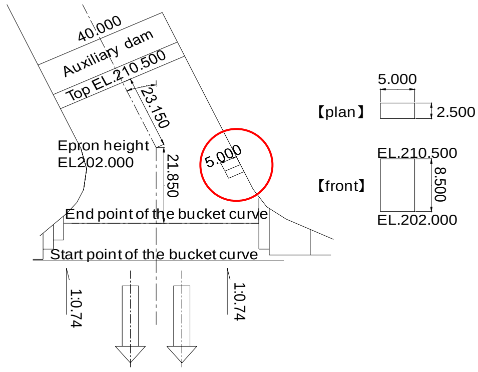

Figure 15. Configuration of energy dissipator

Figure 16. Block to prevent planar eddy currents

3. CONSTRUCTION OF THE SHITSUMI DAM

3.1. Construction of the Dam Body

The Extended Layer Construction Method was used to place the concrete for the dam body. Concrete was transported from the concrete plant on a transfer car (4.5 m^3) and conveyed in a bucket (4.5 m^3) to the dam body with a tower crane installed on each bank of the dam site (15 t crane × 85 m on the left bank and 13.5 t × 75 m on the right bank).

A crawler crane (150 t hoisting) located at the center of the dissipator was used to concrete placing for the dissipator. Concrete was transported by changing buckets, or from the bucket of the left bank tower crane to the bucket (3.0 or 1.5 m^3) on the rail located at the dissipator.

Since the overflow crest or deflector has a complex shape and a small sectional area, structural concrete was used and place with a concrete pump.

3.2. Construction of the Overflow Section

3.2.1. Construction of the overflow crest

As the overflow section is equipped with hydraulic functions, its construction required careful planning and meticulous quality control. In addition, unique ideas were implemented in various stages of the work including reinforcing bar work, formwork, cleaning, and concrete placing.

The overflow crest is shaped as a combination of 1100 R on the upstream side and 1000 R and 5000 R on the downstream side. As it structurally requires high precision in hydraulic functions, curved forms were specially produced and installed over the entire curvature.

The downstream side overflow crest is shaped similar to a combination of the flat and curved portions. Concrete was placed to construct the flat portion first. Then concrete was placed through square openings, 20–30 cm per side, made on the curved forms to construct the curved portion.

About 4 h after the concrete placing, the curved forms were removed, and the placed concrete was trowel-finished by measuring the finished height by survey (Fig.18).

Figure 17. Concrete placement for the overflow section of the dam crest

Figure 18. Finishing of the curved overflow section

3.2.2. Construction of the crest road

As part of the overflow crest in terms of hydraulic structure, the service road on the crest is flat, or has no drainage gradient, in both the longitudinal and transverse directions.

Forms used in the run-off from the overflow part to the non-overflow part included lid forms produced by modifying highly rigid dam forms, and anchors and scaffolds were also placed at a shorter pitch than usual. This arrangement was intended to provide sufficient compaction and reduce the deflection during concreting (Fig.19).

Figure 19. Concreting for the run-off section of the crest road

3.2.3. Construction of the deflector on the downstream side of the dam

The deflector located on the arc of the overflow crest had to be constructed with a sharp top for flushing. Thus, a concrete feeder port, overhanging beyond the design section, was installed to place concrete up to the top, and the concrete was compacted. After casting, the forms and the concrete at the feeding port were removed when the concrete had hardened to the appropriate level, and the part protruding beyond the design section was shaved and finished by manual labor (Fig.20).

Figure 20. Construction of the deflector in the arc part of the overflow crest

The deflector above the regulating spillway outlet was integrally constructed with the dam body. H-beams were arranged to cross the downstream side of the dam body to serve as the receiving platform, and supports were placed on this platform to simplify the support work (Fig 21).

Figure 21. Construction of the deflector above the regulating spillway outlet

3.3. Construction of the Training Wall

The deflector to be installed on the training wall, which overhangs by 1.5 m, was constructed by minimizing the number of horizontal construction joints as priority was placed on structural integrity and visual aesthetics.

Concrete was placed from a tower crane (4.5 m^3 bucket) to construct the wall part down to the lower part (50 cm) of the deflector simultaneously with the dam body. The upper part, including the deflector element, was placed with a concrete pump and piping (Fig.22).

Figure 22. Construction of the training wall at the toe of the dam body (horizontal portion)

Bracket supports were used for the flat part of the deflector overhang, and wedge supports for the sloped part. A movable scaffold was also fabricated, which can be moved by the tower crane, for improved efficiency and safety of formwork assembly and concrete placing (Fig.23).

Figure 23. Construction of the training wall at the toe of the dam body (inclined portion)

4. CONCLUSIONS

The Shitsumi Dam Construction Project was launched in April 1986 and completed in May 2011, 25 years later, when the initial impoundment ended. On March 30, 2011, the water was raised to the surcharge water level in first impoundment, marking Japan's first operation of "All over the dam crest spillway" for a high dam.

An economic design for the body of the Shitsumi Dam was achieved by introducing new technologies including all over the dam crest spillway and free-selective airlock intake.

1) Elimination of road relocation and the use of the free-selective airlock intake eliminated the need to construct a bridge on the crest and thus simplified the structure of the dam crest.

2) Simplification of the crest structure produced a dam with structural features that differed from conventional dams and created a landscape that blended harmoniously with the surrounding mountain forests.

3) In general, although the amount of concrete placing the crest bridge is not large, the construction work was extensive for the size. Simplification of the crest of the Shitsumi Dam provided various advantages in terms of economic efficiency and construction schedule.

4) Three temporary gates, each about 11.8 t in capacity and measuring 7.3 m in breadth, 2.1 m in height and 1.0 m in width, were installed and removed to close the openings of the spillway on the upstream side of the dam body during firs impoundment. At this time, a truck crane (50 t) and trucks (20 t) for carrying materials were operated on the crest road, and no problems occurred.

5) Smooth water flow was achieved over the crest and deflectors as water overflowed during the first impoundment, which demonstrated that the dam functioned as planned.

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