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PLANNING AND DESIGN OF ADDITIONAL DISCHARGE FACILITIES IN JAPAN

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ABSTRACT

Additional discharge facilities to the existing dam are hardly planned in the design and construction stages of the existing dam. The arrangement of additional discharge facilities is restricted due to the layout of the existing facilities of the dam. In this paper, we explain the considerations in the planning and design of the additional discharge facilities in accordance with purposes and types of a facility. In addition, we describe the design approach of additional discharge facilities which are to be installed by drilling a concrete gravity dam.

1. INTRODUCTION

In Japan, because locations for dam construction are limited and will become even fewer in number, demand for making effective use of existing dams is increasing.

One effective method of more effectively using existing dams is to expand discharge facilities in order to reinforce their flood control capacity. Expanding discharge facilities of existing dams were, of course, not planned when these dams were originally constructed. Thus, the arrangement of additional discharge facilities is seriously restricted by the existing facilities of the dam. And in Japan, it is necessary to execute the expansion of the discharge facility of an existing dam while maintaining the functions of the dam, or in other words, while the existing dam regulates floods and supplies water. It is, therefore, necessary to consider installing a large-scale underwater temporary coffering equipment (a large cofferdam), regulating flooding during the construction work, and so on.

This paper first explains the purposes and types of additional discharge facilities for existing dams and gives outlines of important matters to consider during planning and design of such expansion work. It also describes and introduces several examples of methods of designing additional discharge facilities (additional discharge pipes), which are installed by drilling holes in the dam bodies of concrete gravity dams.

2. ADDITIONAL DISCHARGE FACILITIES OF EXISTING DAMS

2.1 Purpose of expanding a discharge facility

The purpose of expanding a discharge facility is to increase discharge capacity which cannot be provided by the existing discharge facility. This can be broadly categorized as [1] improving the functions of an existing discharge facility and [2] responding to modification of flood control and water use plans.

2.1.1 Improving the functions of an existing discharge facility

When large-capacity high pressure discharge facilities were first introduced in Japan during the 1950s, the gates installed on these were designed to operate fully open or fully close. It is, therefore, impossible for these gates to continuously and smoothly regulate the discharge flow rate.

In addition, if the discharge capacity of the normal use discharge facility is small, operation of large spillway gates is required frequently when a small flood occurs. At such dams, it is required to give warning and patrol downstream dams before starting discharge from spillway gates, even if a discharge rate is small. Securing of personnel and organizations for these work becomes a burden. It is necessary to improve such circumstances by installing an additional discharge facility that can control discharge rate smoothly or its discharge capacity is moderate and less than harmless flow rate of downstream rivers. If discharge capacity is less than harmless flow rate, warning and patrol downstream are not required.

2.1.2 Responding to modification of flood control and water use plans

The modification of flood control and water use plans changes discharge conditions of the dam. This is accompanied by the increase of the discharge capacity. And even if the discharge capacity remains unchanged, it is required to discharge water at an even lower reservoir water level.

2.2 Methods of expanding discharge facilities

When expanding the discharge facility of an existing dam, the following methods are considered.

- Cutting the dam body or the crest of the overflow type spillway to install a new overflow crest
- Drilling a hole in the dam body and installing an outlet conduit in the hole
- Installing a new tunnel spillway

2.3 Planning and design of additional discharge facilities

2.3.1 Setting the discharge capacity

The first step is to clarify the discharge flow rate at each reservoir water level considered necessary after expanding a discharge facility in order to achieve the purposes of expanding the discharge facility. The quantity that can be discharged at each reservoir water level by the existing discharge facility is compared with this quantity to clarify the range of reservoir water levels where discharge capacity is insufficient and the discharge quantity shortfall. To effectively use a certain specified flood control capacity for example, it is necessary to ensure flood control capacity in the early stage of flood by discharging water retaining as little as possible in the reservoir within a range that will not cause damage downstream from the dam. For this reason, it is necessary to increase the discharge flow rate while keeping reservoir water level low and the discharge capacity of existing discharge facility at low reservoir water level is often insufficient.

2.3.2 Selecting the type of additional discharge facility

Locations where a discharge facility can be added to a dam body are limited by the layout of the existing dam's discharge facility and the topography surrounding the dam body. The possibility of adding an overflow type spillway or installing an outlet conduit by drilling the concrete dam body are examined accounting for the impact of these factors on the structure of the dam body. When drilling the dam body, there is an upper limit on its diameter imposed by the dam body structure, and a hydraulic limit on the flow velocity inside the pipe, so the discharge flow rate per pipe is also restricted. If the required discharge quantity is not satisfied, it is necessary to increase the number of outlet conduits that are added, but the number of outlet conduits that can be installed is determined by the number of dam body blocks that can be drilled. If it is difficult to add a new discharge facility to a dam body, constructing a new tunnel spillway is considered. When a tunnel spillway is adopted, the tunnel alignment, tunnel diameter etc. are restricted by topographical and geological conditions. The type of discharge facility is selected considering these restrictions to suit to each type.

Figure1 shows the Ikari Dam as an example of adding an outlet conduit by drilling a hole in the dam body. The two gates that can be seen on the lower left of Figure 1 are newly added outlet conduit gates. The alignment of the outlet conduit passing through the dam body is three-dimensionally bent by lowering its elevation towards the gate while varying its orientation towards the existing stilling basin.

An example of a project that cutting the crest of a dam body to install an overflow spillway is the Nagayasuguchi Dam improvement project. As shown in Figure 2, there are now 6 crest gates on the Nagayasuguchi Dam. To increase the discharge capacity at the flood control start water level, the plan calls for the addition of an overflow spillway on the crest of the part of the right bank (left side of Figure 2) . Figure 3 is a view of a hydraulic model test of reconstruction of the Nagayasuguchi Dam. In the plan, from the two additional overflow spillways, a thick water flow is discharged at overflow water depth of about 20 m, which is equivalent to the largest scale in the past in Japan. And the discharged water is bent towards the existing stilling basin by a training wall. These are harsh conditions for the hydraulic design in the modifying of the existing dam.

The Kanogawa Dam improvement Project now being executed is an example of a tunnel spillway. Figure 4 shows the existing Kanogawa Dam. In order to increase discharge capacity at the flood control start water level, a tunnel spillway is now being constructed on the right bank side. Figure 5 shows a hydraulic model test of the improvement of the Kanogawa Dam. The existing Kanogawa Dam is on the right side of Figure 5, and the tunnel spillway discharges water on the left side. A large-scale tunnel spillway with internal diameter of 11.5m is now being constructed to add discharge capacity of about 1,000m^3/s to the existing dam.

And at the Amagase Dam, which is a concrete arch dam, a type whose dam body is not easily modified, a tunnel spillway with internal diameter of 10.3 m is now being constructed.

Figure 1. Ikari Dam

Figure 2. Nagayasuguchi Dam

Figure 3. Hydraulic model testing of the Nagayasuguchi Dam

Figure 4. Kanogawa Dam

Figure 5. Hydraulic model testing of the Kanogawa Dam Improvement Project

2.3.3 Planning and design considering the construction period

In order to expand a discharge facility while operating the dam, the construction plan must absolutely minimize lowering the reservoir water level during construction, and maintain the functions of the existing discharge facility as much as possible. Basically, construction work that impacts discharge capacity should be done so as to minimize its influence in the non-flood season. Furthermore, it is necessary to maintain the maximum discharge capacity of the existing dam during the flood season in order to cope with excess flooding. This also impacts the planning and design of the additional discharge facility. For example, there are cases where the setting of the reservoir water level during construction varies the state of stress around the hole that was drilled in the dam body, causing change of the possible maximum hole diameter. If the hole diameter changes, the discharge pipe diameter also changes, impacting the discharge flow rate from each discharge pipe, and may require a change of the number of discharge pipes.

Construction methods or material transport routes are often limited, for example, it has been impossible to ensure an adequately wide construction yard because of the relationship of the existing dam with the surrounding topography or it has been necessary to transport materials using the reservoir because of the narrow state of surrounding roads. In these ways, expanding discharge facilities while operating the existing dam is severely restricted in various ways, and it is vital to carry out planning and design considering the construction plan in advance.

3. EXPANDING A DISCHARGE FACILITY BY DRILLING A HOLE IN THE BODY OF A CONCRETE GRAVITY DAM

3.1 Placement of the discharge facility

Because a hole is drilled in a dam body and an outlet conduit is installed in the hole, it is impossible to install a gate house, which needs a large space, inside the dam body. Therefore, the outlet conduit is basically a long pressurized pipe with a gate at its downstream end. All examples described later in Section 3.3 are this type. If installing a cofferdam upstream the dam body during construction is considered, it is necessary that its inlet elevation be as high as possible. Considering the ease of construction, the part that passes through the dam body should be as nearly horizontal as possible with little gradient. Because the larger water head makes the higher flow velocity, and to minimize the size of the gate to discharge the same flow volume, it is desirable to lower the gate elevation. As result, a vertically curved alignment is required.

It is economical if the stilling basin of the existing dam can be used for the energy dissipator of the additional discharge facility. So the conduit pipe alignment is also curved horizontally towards the stilling basin of the existing dam. Then, alignment of the conduit pipe is often both vertically and horizontally bent.

In small capacity pipes used for water utilization, the vertical bends and horizontal bends are generally in different locations to prevent the flow inside the pipe from becoming complex,. Locating the vertical and horizontal bends at different parts of a pipe increases its length. In the case of an expansion outlet conduit, lengthening the pipe increases costs because of its large diameter. Lengthening the pipe also shifts the gates downstream, so it is difficult to ensure energy dissipation length of the energy dissipator. In many cases, more excavation of the surrounding natural ground must be executed to install the additional outlet conduit. Therefore, the pipes are required to be as short as possible. Thus, the alignment is often complex, with the vertical bends and horizontal bends combined at the same locations. The pressure etc. that acts on bent pipes on such complex alignment is confirmed by hydraulic model testing.

3.2 Pipe diameter, flow velocity inside the pipe, and inlet elevation

To cope with the problem of dam body stress, normally, the diameter of the hole drilled in the dam body is less than 1/3 of the width of the dam body block. It makes the maximum hole diameter of 5 m when the block width is 15 m. If the pipe construction space and space where rebars are installed to provide reinforcement are subtracted, the maximum pipe diameter becomes about 3.8 m.

To design a small water supply discharge pipe that is buried in a dam body, to prevent cavitation damage, generally the flow velocity inside the pipe is restricted to 10 m/s or less. If the flow velocity inside a 3.8 m diameter pipe is assumed to be 10 m/s, the maximum discharge flow rate per pipe is

113 m^3/s. When a large capacity outlet conduit is added to a dam body, the flow velocity is required to be even higher and the discharge flow rate has to be increased. In that case, it is necessary to carry out a detailed study of the pressure acting on the conduit pipe wall surface, which is focused on bends where negative pressure occurs easily.

To design the cofferdam and to deal with the dam body stress, the discharge pipe's inlet elevation should be as high as possible. But in order to prevent air entrainment from the inlet and the occurrence of negative pressure in the inlet bell mouth, the discharge pipe's inlet should be as low as possible in order to increase the head water depth at the inlet when the water surface is at the lowest water level of the reservoir. In some cases, as a result of lowering the inlet elevation to increase the depth at the inlet at the lowest water level and analyzing the dam body stress, it is necessary to reduce the pipe diameter in order to satisfy stress conditions of dam body. In that case, the relationship between the flow velocity inside the pipe and the pressure drop in the bell mouth must be considered carefully.

The discharge flow rate from a circular pipe Q is as shown below

$$Q = AV = \frac{\pi}{4} D^2 V \qquad (1)$$

Where; A: pipe section area, V: flow velocity inside pipe, D: pipe diameter, so;

$$V = \frac{Q}{\frac{\pi}{4} D^2} \qquad (2)$$

On the other hand, the quantity of pressure drop in the bell mouth Δh_b is as shown below.

$$\Delta h_b = f_b \frac{v^2}{2g} \qquad (3)$$

Where; f_b: bell mouth loss coefficient, g: gravity acceleration, so if the flow volume Q is constant;

$$\Delta h_b \propto \frac{1}{D^4} \qquad (4)$$

If the pipe diameter D is small, the quantity of pressure drop in the bell mouth Δh_b increases inversely proportional to the fourth power of the pipe diameter D.

In a case where according to results of dam body stress analysis, the pipe diameter must be reduced, it is necessary to increase the flow velocity inside the pipe to ensure discharge capacity. As a result, the pressure drop at the bell mouth increases, and lowering the outlet elevation is not necessarily advantageous.

3.3 Examples of expansion of discharge facilities

Major cases of the expansion of discharge facilities by drilling a hole in the body of a concrete gravity dam are introduced below (refer to Table 1).

The first case is the project of the expansion of the water supply use discharge facility at Yoroihata Dam (expansion construction period: 1988 to 1990) (Higuchi et al. 1991) by the Ministry of Land, Infrastructure, Transport and Tourism. An additional outlet conduit is installed in the drilled hole of a concrete gravity dam by the help of a cofferdam arranged at upstream the dam while maintaining the reservoir's functions. This discharge facility was installed in order to pass water supply discharge of 69.1 m^3/s from the Tamagawa Dam constructed upstream the Yoroihata Dam. The additional outlet conduit at the Yoroihata Dam has a pipe diameter of 3.2 m, and the drilled hole diameter of 4.4 m, and the design concept of a small capacity water supply outlet pipe has been followed, restricting the flow velocity inside the pipe to less than 10 m/s.

The spillway expansion at the Tase Dam (expansion construction period: 1994 to 1998) (Shimada & Kakizaki 2001) was executed to improve the dam's flood control operation. The Tase Dam, which was completed in 1954, has four high pressure outlet conduits for flood control that are equipped with

Japan's first high pressure slide gates which were imported from the United States. When this dam was constructed, high pressure slide gates were operated fully open and fully closed, and the discharge flow rate was varied in steps by changing the number of outlet conduits discharging water. Therefore, a discharge facility with a high pressure roller gate that can be used to control the discharge flow rate in stepless manner by discharging through partial open gate was installed in the hole drilled in the dam body. It became possible to control discharge rate in stepless manner by also using the existing outlet conduits for flood control. With outlet conduit diameter of 3.6 m and hole diameter of 5.0 m, it is a large capacity outlet conduit with discharge capacity of 130 m^3/s. The flow velocity inside the pipe is about 13 m/s, which is higher than that at the Yoroihata Dam. To design the outlet conduit, the pressure acting inside the pipe was confirmed by hydraulic model testing.

Table 1. Major Examples of Outlet conduit Expansion of Concrete Gravity Dams by the Ministry of Land, Infrastructure, Transport and Tourism

Dam name	Yoroihata	Tase	Ikari	Tsuruda
Dam height	58.5 m	81.5 m	112.0 m	117.5 m
Dam crest length	236.0 m	420.0 m	261.8 m	450.0 m
Dam body volume	192,000 m^3	437,000 m^3	468,000 m^3	1,119,000 m^3
Year dam body completed	1957	1954	1956	1965
Pipe shape	Circular	Circular	Circular	Circular
Pipe diameter	3.2 m	3.6 m	3.8 m	4.8 m
Hole section shape	Circular	Horseshoe	Horseshoe	Rectangular
Hole section width	4.4 m	5.0 m	5.0 m	6.0 m
Hole section height	4.4 m	5.0 m	5.0 m	6.0 m
Hole section length	29 m	41 m	50 m	54 m
Number of pipes	1 pipe	1 pipe	2 pipes	3 pipes

The spillway expansion at the Ikari Dam (expansion construction period 1998 to 2002) (Hachisuka 2002) was implemented to adapt to the change of the flood control plan following the completion of the Yunishigawa Dam upstream from the Ikari Dam. The existing spillway of the Ikari Dam was equipped with the first high pressure slide gate manufactured in Japan, which is the same kind of gate as that at the Tase Dam described above. Therefore, as at the Tase Dam, it was installed as part of improvement of the flood control operation. The pipe diameter is 3.8 m, and the hole diameter is a maximum of 5.0 m, which is described above. Discharge volume of 500 m^3/s was required for the two additional outlet conduits at the Ikari Dam, and the flow velocity inside the pipe was as high as more than 22 m/s. So the Public Works Research Institute carried out the fundamental research in order to clarify the properties of the pressure acting on the wall at bends in the pipe and examined the implementation design shape of additional outlet conduits by hydraulic model testing. It is impossible to do bending work of large-scale steel pipe, so bent pipe is made by linking straight pipes cut diagonally. It was considered that a local pressure drop occurs near bends at the connections of these straight pipes. Therefore the relationship of the bending angle of the straight pipe connections with the pressure drop properties were examined, and a method of estimating the pressure drop near the straight pipe connections was proposed and reflected in the design.

The additional outlet conduits now being constructed at the Tsuruda Dam is, based on detailed dam body stress analysis, pipes with diameter of 4.8 m inside holes with diameter of 6.0 m, which is even larger than at the Ikari Dam. In order to ensure flood control function during construction of the improvement of the existing energy dissipator, the additional discharge facilities including the energy dissipator for additional conduits will be completed first. Figure 6 shows redevelopment work at the

Tsuruda Dam. Figure 7 is a view of hydraulic model testing that the Public Works Research Institute carried out to study the redevelopment of the Tsuruda Dam.

Figure 6. Tsuruda Dam Redevelopment Work (now in progress)

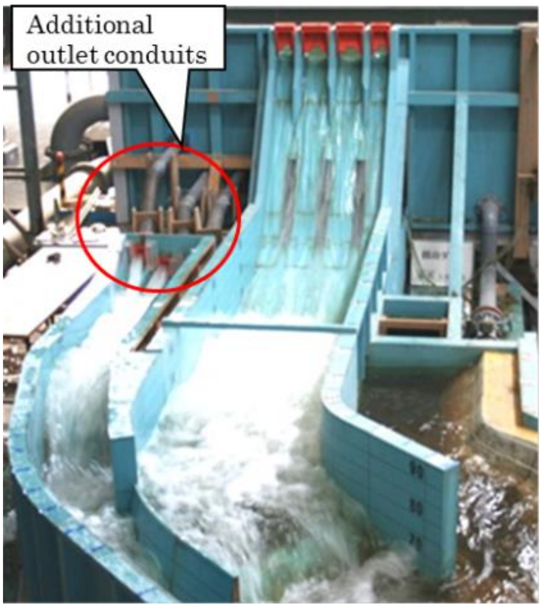

Figure 7. Hydraulic model testing of the Tsuruda Dam Redevelopment Project

4. CONCLUSION

To expand the discharge facility of an existing dam, it is necessary to carry out planning and design while considering a variety of conditions: such as the layout of the discharge facility at the existing dam, surrounding topography, ensuring roads to transport materials and equipment, an construction plan that considers ensuring reservoir capacity and flood control operation necessary to maintain the functions of the dam during construction, and an operation method that integrates the existing discharge facility. Therefore, it is important to carry out the topographical and geological survey around the construction site and a structural study of modified dam body, and to continuously adjust the construction plan, and also to feed back the results of these studies to the planning and design of the additional discharge facility.

For the planning and design of a project to improve an existing dam, it is even more important to cooperatively exchange information for engineers who are experts on geology, structures, hydraulics and construction planning than it was during past dam construction projects. It is probably correct to state that improvement of dams while they continue operating is the culmination of technical capabilities in these various fields.

5. ACKNOWLEDGEMENTS

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