HYDRAULIC DESIGN IN UPGRADING DAMS UNDER OPERATION

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ABSTRACT: In Japan, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) presented a "MLIT's Vision to Upgrade Dams under Operation" in June 2017. The vision introduces countermeasures to advance the upgrading of existing dams by applying both structural and non-structural measures to ensure that they are used more effectively than in the past.

There are cases raising the dam body and increasing the discharge capacity of the discharge facilities etc. in the past. At some existing dams, improvement projects are currently under construction.

There are challenges in hydraulic design of improvement and additional construction of discharge facilities in dam upgrading different from the construction of a new dam. Methods to cope with these challenges have been examined by hydraulic model experiments and so on. In this report, the outline of three major technologies to increase the discharge capacity in dam upgrading, cutting dam body, drilling dam body and tunnel spillway, are introduced. And taking Nagayasuguchi dam remodeling project as a representative example, the contents of the hydraulic design of the existing dam redevelopment project are explained.

Keywords: Dam upgrading, Increase of discharge facility, Cutting dam body, Drilling dam body, Tunnel spillway, Hydraulic design

1 Introduction

In Japan, dams completed so far played a major role in both flood control and water use. On the other hand, it is becoming more important to effectively utilize existing infrastructure stocks while reducing the total cost, under the constraints of a falling productive-age population and a severe financial situation. Based on this recognition, MLIT presented a "MLIT's Vision to Upgrade Dams under Operation" in June 2017 [1]. The vision introduces countermeasures to advance the upgrading of existing dams by applying both structural and non-structural measures to ensure that they are used more effectively than in the past (Table 1).

Regarding "(4) Improving Facilities for a more Advanced Functionality" listed as one of the measures, there are cases raising the dam body and increasing the discharge capacity of the discharge facilities etc. in the past. At some existing dams, improvement works are currently under construction.

There are challenges in hydraulic design of improvement and additional construction of discharge facilities in dam upgrading different from the construction of a new dam. Methods to cope with these challenges have been examined by hydraulic model experiments. In this report, the outline of major technologies to increase the discharge capacity in dam upgrading is introduced and the contents of the hydraulic design of the existing dam redevelopment project are explained, taking Nagayasuguchi dam remodeling project as a representative example.

Table 1: Measures to develop and accelerate dam upgrading

(1) Life Extension of Dam
(2) Promoting Efficiency and Advancement of Maintenance
(3) Flexible and Reliable Operation to Optimally Utilize the Capacity of the Facility
(4) Improving Facilities for a more Advanced Functionality
(5) Responding to Climate Change
(6) Addition of Hydropower
(7) Conservation and Revitalization of River Environment
(8) Regional Promotion utilizing the Dams
(9) Promoting Dam Upgrading Technologies Overseas
(10) Development and Implementation of Technologies to Promote Dam Upgrading

2 Technologies to increase the discharge capacity

In the facility improvement of the existing dams, efforts to increase discharge facilities and to raise dams are being carried out for various reasons, such as changing the flood control plan, changing the water usage plan, and improving functions and so on. The outlines of three technologies, which are typical when increasing comparatively large capacity of discharge capacity, improvement of the crest discharge facilities, improvement of the discharge facilities in a dam body and constructing new tunnel spillways are described as bellow.

2.1 Improvement and expansion of the crest discharge facilities (cutting dam body)

This technology is to improve or expand the overflow type discharge facilities installed at the crest of the dam and the orifice type discharge facilities with a design water head of 25 m or less. The technique of cutting from the top of the dam body is often used. Since the remodeled part is near the top of the dam, there are few problems concerning dealing with large water pressure. In addition, if it is not necessary to install a temporary coffering facility by lowering the reservoir level, construction work becomes relatively easy.

In the dams constructed early period, both the flood control spillway and the emergency spillway may be adopting a discharge facility with a gate. In such dams, when the catchment area is small and the flow rate increases rapidly during flood, the discharge facility is remodeled gateless type facility in order to improve the certainty of the flood control function.

Remodeling to gateless will also reduce the burden of operation and maintenance. In order to remodel the emergency spillway to gateless type, the method to expand the overflow width is usually adopted. The challenges of this method are whether it can be placed at the top of the dam body, or whether it can safely flow down to the downstream river channel by dissipating the discharged water flow energy. In order to solve these challenges, a new emergency spillway is installed on the lake bank in the reservoir, or a training wall is installed on the downstream of the dam along with the expansion of the overflow width at the dam crest.

As a case with a purpose other than increase the discharge capacity, at the Yamasubaru dam and Saigo dam in Miyazaki Prefecture (managed by Kyushu Electric Power Co.), to improve the function of passing through sediment, cutting down the existing dam body and remodeling the discharge facilities are in progress.

Regarding the method of cutting the dam body, Nagayasuguchi dam in Tokushima Prefecture (managed by MLIT), which is undergoing remodeling work, is the largest case in terms of cutting depth in history in Japan. It is planned to cut the dam body at the maximum depth of about 37 m and to install two additional discharge facilities. As for Nagayasuguchi dam, it is described the content of hydraulic design in chapter 3.

2.2 Improvement and expansion of discharge facilities in a dam body (drilling dam body)

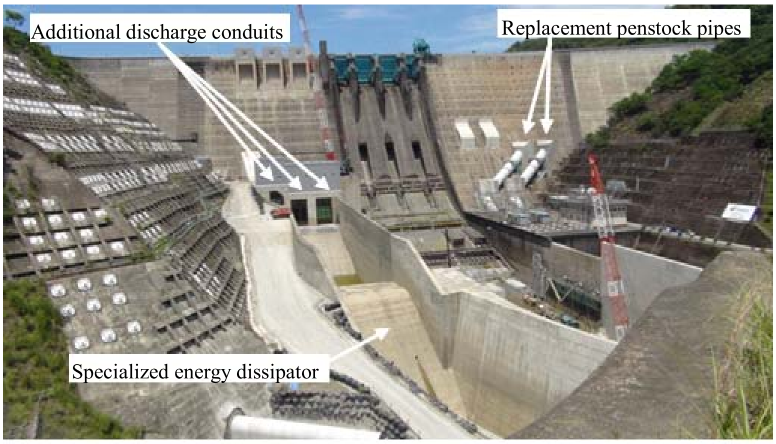
This technique is to drill a hole in an existing dam body and to install an additional discharge facility. Usually it is applied to a gravity type concrete dam. In Japan, it is sometimes difficult to lower the reservoir level due to restrictions on the reservoir operation for the purpose of water use, and construction under large water depth conditions is required, so the technology of a temporary coffering upstream side of the dam is important.

A discharge facility with an acting water head exceeding 25 m is defined as a high pressure discharge facility and the flow velocity becomes high speed during discharge, so it is necessary to prevent cavitation damage due to a local negative pressure generation. For that purpose, it is required to reduce the flow velocity inside the pipe, but since the size and numbers of holes that can be drilled in the dam body are restricted by the dam structure, from the economical point of view, increasing the flow velocity to increase the discharge capacity is advantageous. Furthermore, it is difficult for the additional discharge facility to arrange the inlet and outlet of the discharge pipe straight on the relationship with the arrangement of the existing discharge facilities. In this case, a complicated curved shape is adopted, but a local pressure drop tends to occur in the curved part of the large diameter discharge pipe. In order to cope with these problems, the examination of the water pressure acting at the inside wall of the bending part by a hydraulic model experiment was carried out [2]. Currently, it is possible to do rational design.

As an example of drilling of the dam body, the remodeling of Tsuruda Dam in Kagoshima prefecture (managed by MLIT) is the largest scale previously recorded in Japan. Three additional discharge conduit pipes (diameter: 4.8 m, drilled cross section: height 6.0 m and width 6.0 m) and two replacement penstock pipes for power generation (diameter: 5.2 m, drilled cross section: height 6.4 m and width 6.4 m) will be installed (Figure 1). In the temporal coffering work at the construction of the remodeling of Tsuruda Dam, in addition to the conventional construction method of assembling the steel coffering gates after installing the foundation pedestal concrete in the water upstream of the dam, a new technology of a floating type coffering facility requiring no pedestal was developed. As a result, large depth diving work was reduced, cost reduction and safety assurance were achieved.

If the discharge rate of discharge facility in a dam body is small, it can be discharged to the existing energy dissipator, but in the case of large scale facilities such as Tsuruda Dam, a specialized energy dissipator is newly constructed.

As for Tsuruta Dam, as well as Nagayasuguchi dam, the hydraulic design was examined while confirming the flow condition by the hydraulic model experiments (Figure 1).



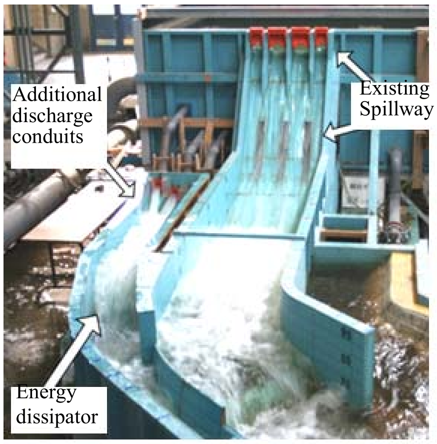


Figure 1: Construction situation of Tsuruda dam (June 2017) (left) and hydraulic model (right)

2.3 New construction of tunnel spillway

When it is difficult to cut or drill the existing dam body due to restrictions on dam type and dam structure in order to add large capacity discharge facilities, it is selected to construct a new tunnel spillway in the mountains around the dam. As a representative example, there are two dams of Kanogawa dam in Ehime prefecture and Amagase dam in Kyoto prefecture. Both dams are managed by MLIT and are currently under remodeling construction.

The tunnel spillway of Kanogawa dam is 11.5 m in tunnel diameter, 457 m in length, about 1,000 m^3/s in discharge capacity. The tunnel spillway of Amagase dam is 10.3 m in tunnel diameter, 617 m in length, about 600 m^3/s in discharge capacity.

Because they are long pipe channels acting relatively large hydraulic pressure, they were designed as pipe flow facilities where the cross section of the tunnel channels were large and the flow velocities were suppressed to around 10 m/s. Due to the pipe flow, air suction at the inflow portion may cause vibrations of the gate at the outlet and disturbance of the flow condition. In order to reduce air suction, it is necessary to deepen the position of the inflow part, but since they are large-scale facilities and such arrangements are difficult, inlet part shapes were examined by the hydraulic model experiment to suppress the generation of the suction vortex.

In construction of the inlet part in the reservoir of Amagase dam, a shaft-type underwater working machine which can perform excavation work and so on underwater by remote control from the land developed by a private company was adopted.

Both dams' facilities have large discharge capacities and need energy dissipators, but due to constraints on the arrangement within the downstream river channel, Kanogawa dam has a compact designed stilling basin with steps and baffle piers (Figure 2), the energy dissipator of Amagase dam will be installed as underground type in the mountains.

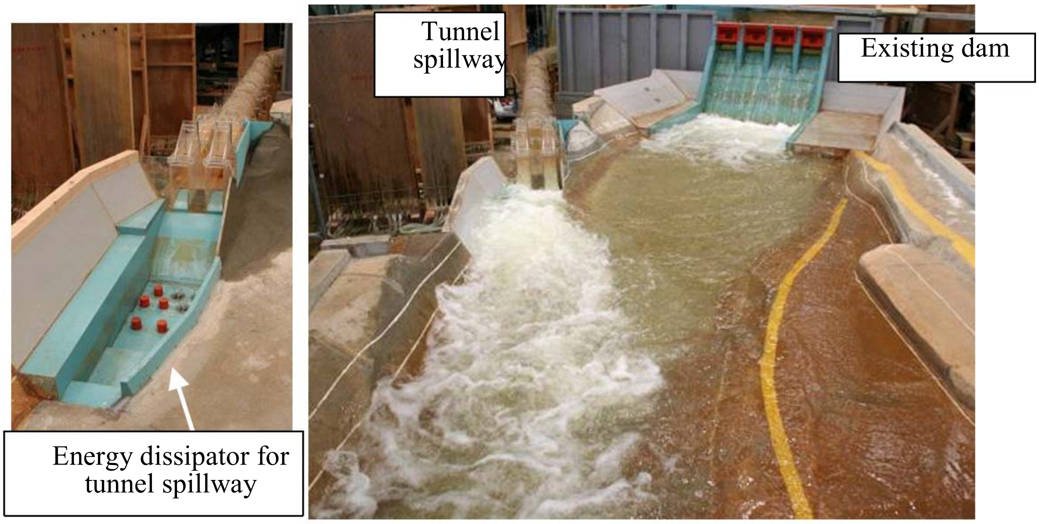


Figure 2: Hydraulic model experimet situation of Kanogawa dam tunnel spillway

3 Hydraulic design in Nagayasuguchi dam remodeling project

3.1 Outline of Nagayasuguchi dam remodeling project

Nagayasuguchi dam is a multipurpose dam built in 1956 in Tokushima prefecture for flood control, power generation and irrigation water supply. The dam type is a gravity type concrete dam, with the dam height 85.5 m, total water storage capacity 54,278,000 m^3, effective water storage capacity 43,497,000 m^3, catchment area 538.9 km^2. Nagayasuguchi dam remodeling project is to modify the dam for the purpose of increasing the flood control capacity, maintaining of normal function of the river water flow and improving the water quality of the discharged water [3]. Regarding the increase of the flood control capacity, based on the flood control plan of the Nakagawa River System, in order to secure the flood control capacity required, a part of the dam body on the right bank will be cut out and the two additional new spillways will be installed (Figure 3).

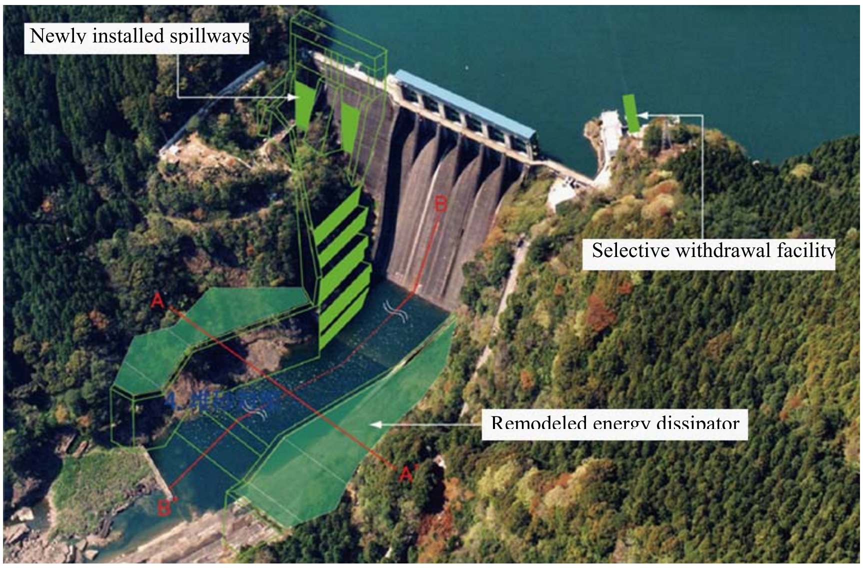


Figure 3: Outline of Nagayasuguchi dam remodeling project

3.2 Hydraulic design by hydraulic model experiments

The hydraulic design by hydraulic model experiments of the newly installed spillways of Nagayasuguchi dam remodeling project was carried out at the Public Works Research Institute from 2008 to 2012. It was confirmed that required functions and safety as described below were secured under conditions such as predetermined water level and discharge rate; whether the required discharge capacity is secured, whether the water pressure acting on facilities such as the training channel part and the energy dissipator is within an allowable range, and whether a stable flow situation is formed. In the case that they were not secured, the design of the facilities was revised.

Specifically, the examinations on the overflow crest part, the training channel part, the energy dissipator (the existing facilities and newly installed facilities released flood discharges merge with each other) and the downstream river channel were implemented (Figure 4).

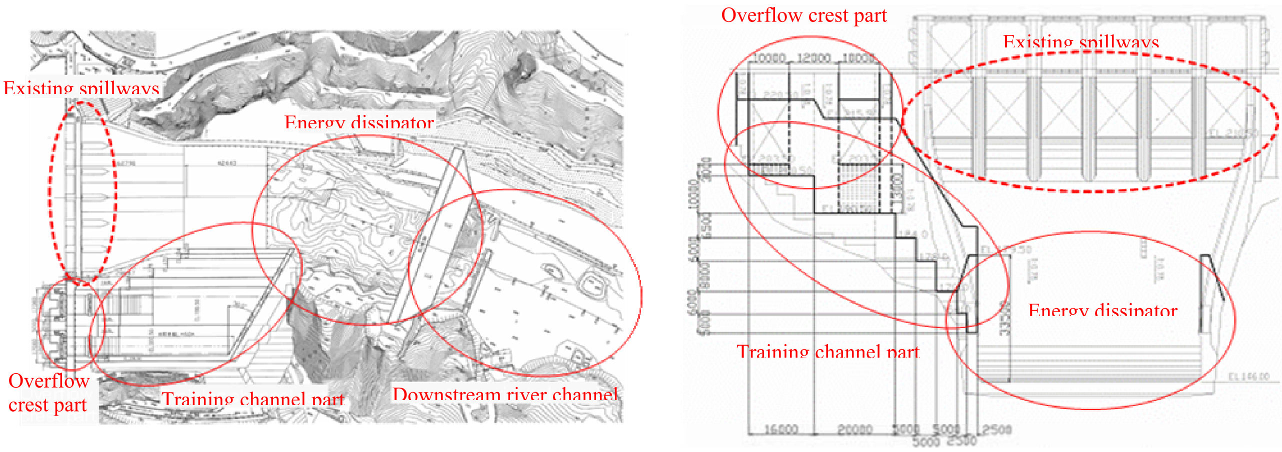


Figure 4: Plan view (left) and downstream view (right) of the original design shape

First, a hydraulic model of the original design shape by desktop design work was created, water was flowed under conditions of predetermined water level, discharge rate, etc., and flow conditions were checked. The overflow crest part was important to determine the flood control function of the dam, it was necessary to confirm whether a predetermined discharge rate was able to discharge at a predetermined water level and derive a relational equation between the water level and discharge rate. Usually, it is studied with a large scale partial model (Figure 5), which extracts only the overflow crest part, apart from the whole model (Figure 5) including the other parts of discharge facilities.

Figure 6 shows the situation of the hydraulic model experiment with the original design shape of Nagayasuguchi dam.

The following problems were recognized from the experimental results of the original design. In the overflow crest part, the discharge rate at the predetermined water level was insufficient. At the training channel part, the water flow from the overflow crest hit the training wall with momentum and dropped to the energy dissipator (stilling basin) without energy dissipation. In the original design shape of the energy dissipator installing only sub-dam, the water stream on the left bank largely creeped up in the area where the discharged water from the existing spillway merged into the discharged water from the newly installed spillways.

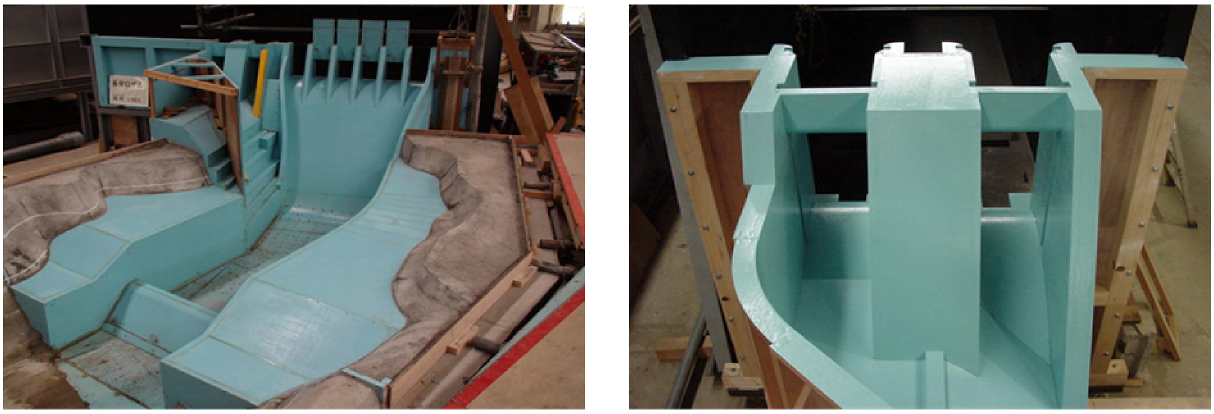


Figure 5: The whole model (scale:1/62.5) (left) and the patial model of crest part (scale:1/40) (right)

Figure 6: Flow stiation of hydraulic model experiment (training channel part: original desgin)

In order to improve these problems in the original design shape, as for the overflow crest part, by lowering the overflow crest top height on the river side discharge facility and changing the shapes of the overflow crests from the trapezoidal overflow spillway to the standard shape of overflow spillway, the required discharge rate was secured.

Regarding the training channel part, various shapes such as changing the position and angle of the training wall, installing the slope and so on had been examined trial and error. The final shape that separates and diffuses the discharged water from both spillways of the mountain side and the river side was developed. As a result, the water level of the training channel part could be kept low and the height of the training wall could be reduced.

As for the energy dissipator, a safe design shape for the dam and the downstream river channel was obtained by improving the planar shape and installation of the side channel walls. The final design shape is shown in Figure 7, and the situation of the hydraulic model experiment with the final shape is shown in Figure 8.

In addition, as shown in Figure 9, examinations on the flow situation in the case where discharge from existing spillways occurred during the construction of the new energy dissipator were also conducted by hydraulic model experiments.

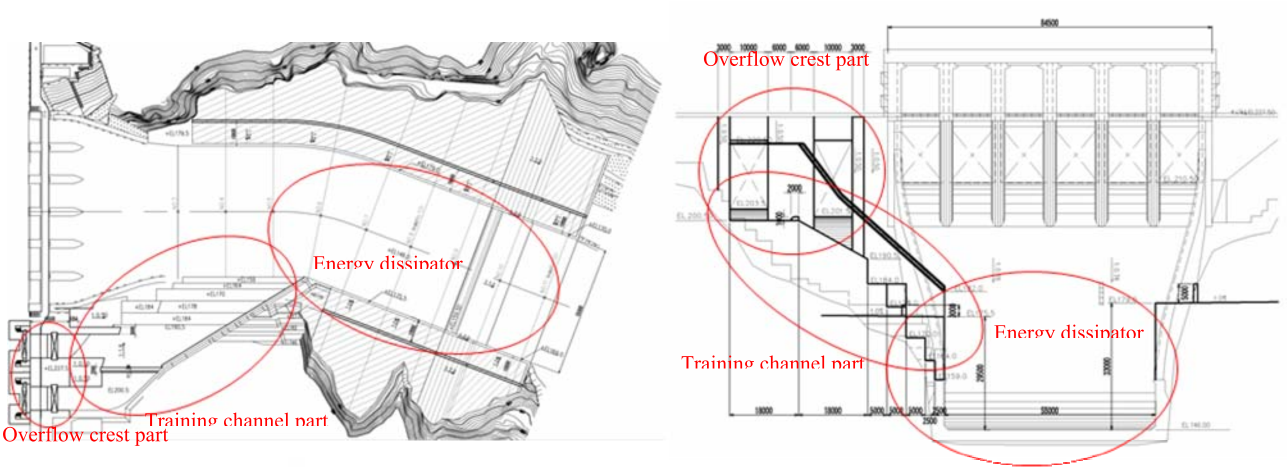


Figure 7: Plan view (left) and downstream view (right) of the final design shape

Figure 8: Flow stiation of hydraulic model experiment (training channel part: final desgin)

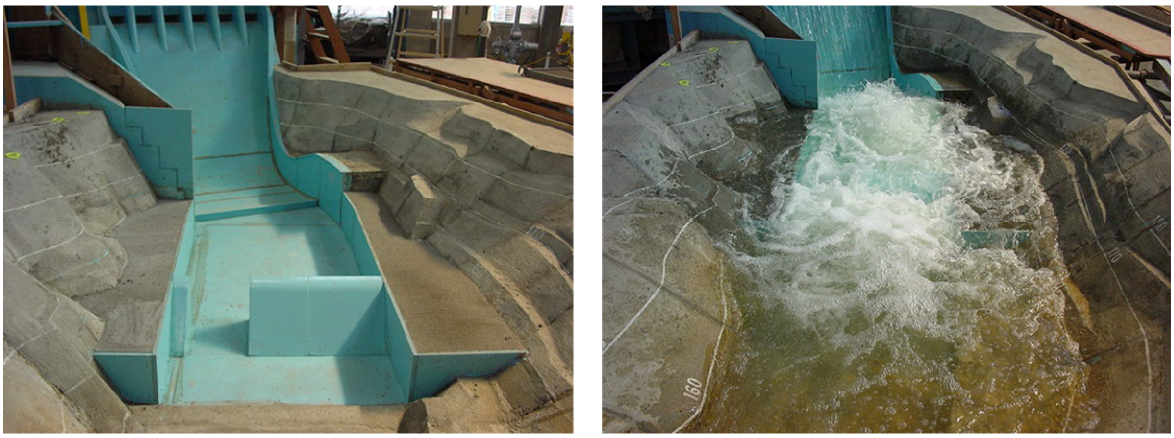


Figure 9: Flow stiation of hydraulic model experiment of the construction stage

4 CONCLUSION

In the hydraulic design for upgrading dams, it is important to secure the required discharge function and to ensure the safety of the dam body and the downstream river channel with respect to the flow condition downstream of the dam which changes greatly due to an increase of discharge capacity.

In addition, since it is necessary to carry out the remodeling construction work while operating the existing dam, the examinations how to secure the function of the existing dam under construction and how to minimize the influence of discharge from the existing dam on construction work are important.

Regarding the technologies to increase the discharge capacity in Japan, in the past few years, the largest historical projects of three representative methods of cutting dam body, drilling dam body and tunnel spillway have been started and are currently under construction respectively. Many technical experiences and knowledge have been accumulated in various fields through the implementation of these designs and constructions, and it is expected to be utilized them for future upgrading dams under operation.

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