An Experimental Study on the Applicability of Outlet-Controlled Siphon Spillway for Improvement of Dam Function

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1. Purpose of Research

In view of recent climate change and intensification of floods, the necessity for advance discharge is increasing, therefore dam upgrading project to increase discharge capacity is urgently needed in Japan. In general, when a new spillway is installed on the dam body, large-scale temporary facility is required on the upstream surface where the inlet is located. By arranging a siphon spillway on the dam body, it is possible to increase the number of discharge facilities more easily than a discharge pipe that drills the dam body. Japan Dam Engineering Center, HOKOKU KOGYO Co., Ltd., and CTI Engineering Co., Ltd. are jointly developing a new technology for siphon spillways that maintains siphon state by installing a gate at the outlet (Facility of Dam Spillway. Patent pending, application number 2019-209304).

In this research, Hydraulic Model Test was carried out to study the feasibility of the outlet-controlled siphon. In the experiment, the hydraulic characteristics assuming the operation and design of the facility were observed, such as the condition in which the siphon flow can be maintained, and the negative pressure is generated as a factor of cavitation failure.

2. Method of Research

2.1 Overview of Outlet-Controlled Siphon Spillway

Siphon spillways used in dam spillways are often installed without gates and emergency spillways, and as the reservoir water level rises, the flow in the pipe changes from open channel flow and transitional flow to siphon flow (pipe flow). Since the dominant cross section of the transitional flow is not clear, the relationship between the reservoir water level and the discharge amount cannot be particularly determined.

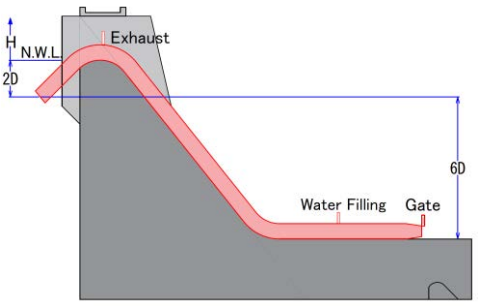

Figure 1 Outline of Siphon Spillway

In this research, the siphon flow can be easily maintained at the operating water level by adjusting the gate opening according to the reservoir water level.

2.2 Setting the assumed model

In this study, the following facilities were assumed:

・The siphon spillway is placed along the existing dam body.

・The target flow rate is about 100 m^3/s and the siphon pipe diameter is 3m.

・It was assumed that the curved tube was always full water level (top of the crest), and the center position of the inlet was 2D below the full water level.

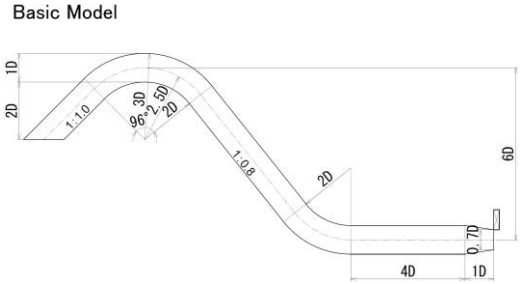

Figure 2 Shape of Siphon Model

Based on the above, the model tube diameter is 150mm, and the assumed scale is 1/20. (See Figure 2)

Keyword *Upgrade Dams, Siphon, Hydraulic Model, Expansion of Discharge Facilities*
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2.3 Experimental method, experimental conditions, measurement contents

In the Model Test, the siphon state is formed by forced exhaust from the tube at the top of the pipe. Then, the gate opening is set to a predetermined degree and the water supply amount is adjusted to reach a predetermined reservoir water level. After confirming steady-state situation, measurement was performed. Experimental conditions and measurement contents are shown in Table 2 and Table 3.

Table 1 Hydraulic Condition

TERMS	CONDITION
Reservoir Water Level	-1D～+6D Total Head (4.5D～8.5D)
Degree of Gate Opening	100%, 75%, 50%

Table 2 Measurement Terms

TERMS	MEASUREMENT METHOD
Reservoir Water Level	Point Guage
Discharge	Rectangle Weir
Water Pressure acting on pipe wall	Piezo Pipe

3. The Results of Model Test

Figure 3 shows the minimum pressure of the siphon pipe in relationship with the water level and discharge rate for each gate opening. In this figure, the green line represents the current Japanese standard of -3mH_2O pressure. The operable range is above the green line based on the current standards. The area below the red line is unstable due to air entrainment. In this range, increased air can cause vibrations in the siphon pipe and affects the maintenance of the siphon condition. The blue line represents the US standard of -7.3mH_20 [1], and it is possible to expand the operable range to the yellow area by easing the standard of the allowable negative pressure. The orange area is an uneasy area, but it was confirmed that the red line can be lowered by reducing the gate opening, and the operable range can be further expanded.

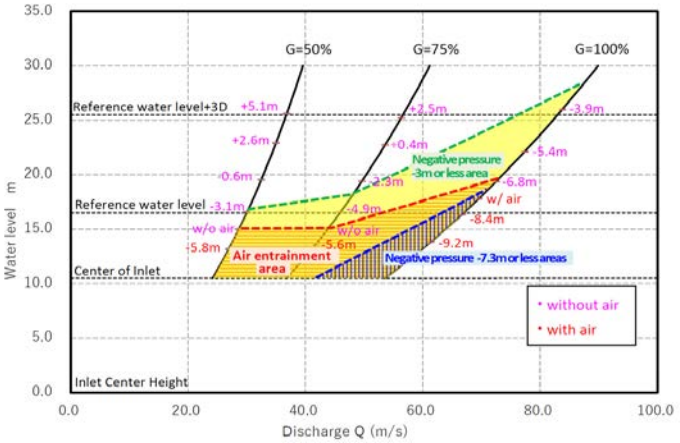

Figure 3 Flow conditions, pressure, and discharge chart

Photograph 1 Siphon Spillway Model

4. Applicability to dam discharge facilities and future challenges

It was confirmed that it is necessary to maintain the siphon flow at a low water level by gate adjustment. It can be concluded that siphon spillway is applicable as a temporary facility such as a storage discharge facility, a water level lowering discharge facility, and a commutation facility with a relatively small discharge.

In the future, research on the evaluation of the risk of negative pressure and effect on the operable range by extending the inlet downward, and vibration countermeasures at the inlet extending to the reservoir are being considered.

5. Acknowledgement

The researchers would like to express utmost gratitude to Mr. Hideaki KAWASAKI of Japan Dam Engineering Center, and HOKOKU KOGYO Co., Ltd. for the valuable advice and support provided during this research.

[1] Elmer Rock, Design of a High-Head Siphon Spillway, ASCE, January 1940