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The Effect of Wedge-Type Baffle Block Attenuation on the USBR IV Stilling Basin

Awan Risdiyanto, Adi Prawito

Civil Engineering Department, Narotama University, Surabaya, INDONESIA

E-mail: awan.risdiyanto@narotama.ac.id, adi.prawito@narotama.ac.id

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ABSTRACT

The USBR Type IV weir is designed for oscillating hydraulic jump weirs with a Froude number between 2.5 and 4.5. The weir components include a chute block and end sill without a baffle block. In testing the USBR Type III weir model with a Froude number approaching 7.07, a wedge-shaped baffle block with a 120° apex angle and 90° side angle cuts created a supercavitation shape, a very sharp flow discontinuity, resulting in more intense turbulence and energy dissipation in the hydraulic jump weir compared to a rectangular baffle block. Wedge-shaped baffle blocks can be placed closer to the spillway foot, thereby increasing their effectiveness in dissipating more high-velocity flow energy and avoiding the formation of wave formations that could potentially cause scouring downstream of the end sill, as in the case of rectangular baffle blocks, thus helping to shorten the length of the stilling basin. To determine the effectiveness of wedge-shaped baffle blocks in a weir with a Froude number between 2.5 and 4.5, it is necessary to test the energy dissipation model resulting from the placement of wedge-type baffle blocks on oscillating hydraulic jumps.

Keywords: froude number, baffle block, wedge type, energy dissipation, oscillating hydraulic jumps.

INTRODUCTION

A hydraulic jump is a change in flow from supercritical to subcritical. The process of a hydraulic jump begins when a high-velocity supercritical flow encounters a slower subcritical flow, causing a sudden deceleration. A hydraulic jump forms as the water surface elevation increases due to the deceleration. Hydraulic jumps can be classified into at least four different types based on the Froude number of the inflow. The types of hydraulic jumps are: irregular, weak, oscillating, stable, and strong [1]-[3].

An analysis of the natural hydrodynamic forces acting on the bottom slab of a surge tank due to water turbulence shows that the location where maximum turbulence occurs varies and is highly dependent on the Froude number of the incoming flow [4]. The USBR Type IV stilling basin is designed for stilling basins with a Froude number between 2.5 and 4.5. The stilling basin equipment includes a chute block and end sill without a baffle block [1]-[3].

The baffle block type stilling basin is also designed for stilling basins with a Froude number between 2.5 and 4.5. This stilling basin is equipped with a tall square baffle block, which is a weakness of this stilling basin because floating and suspended sediment can get stuck and cause the basin to overflow and damage the baffle block [5].

Studies on standard square-shaped baffle blocks, as recommended in the USBR Type III guidelines, have shown that they are prone to cavitation damage when used in dams with moderate to high heads, where flow velocities at the stilling basin bottom are very high. This study proposes changing the geometry of the baffle blocks from a cube or square shape to a wedge [6].

Research on flow through baffle blocks, energy dissipation, cavitation, and erosion comparison in USBR Type III weir model testing with a Froude number approaching 7.07 on square and wedge baffle blocks shows that wedge baffle blocks with a 120° apex angle and side angle cuts of 90° creates a super cavitation shape, a very sharp flow discontinuity, resulting in more intense turbulence and energy dissipation in the hydraulic jump weir compared to rectangular baffle blocks. The wedge-shaped baffle block can be placed closer to the spillway foot, thereby increasing its effectiveness in dissipating more high-velocity flow energy and avoiding the formation of wave formations that could potentially cause scouring downstream of the end sill, as in the case of rectangular baffle blocks, hereby helping to reduce the length of the stilling basin to only about half (1/2) the length of a USBR Type III stilling basin [7].

A flood-control dam is a hydraulic structure specifically designed to reduce downstream flood risk by temporarily storing excessive runoff and releasing it at a controlled rate. Unlike conventional water-supply dams, its reservoir is generally operated to preserve sufficient flood-control storage capacity, particularly during the rainy season [8]-[10]. When intense rainfall generates a flood wave, the reservoir captures part of the inflow, reducing and delaying the downstream peak discharge. FEMA describes dams as structures that impound water and reduce downstream flow, while their design commonly incorporates controlled outlets and emergency spillways to manage extreme events [11]-[13].

The dam should be designed using hydrological analyses of design floods, reservoir routing, spillway capacity, dam stability, and downstream consequences. Effective operation also depends on rainfall and river-level monitoring, forecasting, and clearly defined operating rules. Recent World Bank guidance emphasizes dynamic reservoir operation and hydrometeorological forecasting to improve flood attenuation under changing climatic conditions [14]-[16].

RESEARCH METHODS

In this study, the methods used systematically can be seen in the research flowchart as shown in Figure 1. The research steps taken are as follows:

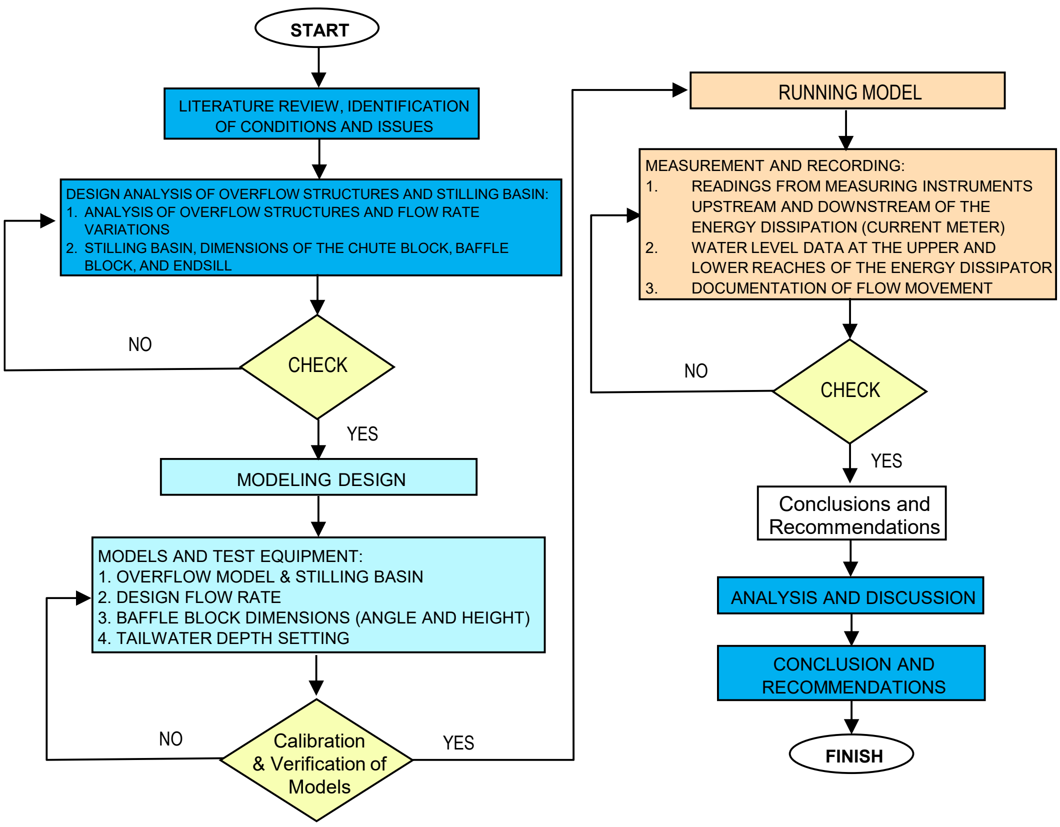

Figure 1. Research Flowchart

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Model Description

In this energy dissipator design analysis, Series Model 0 and a Type IV USBR stilling basin were used as the basis for calculating the dimensions of the chute block, endsill, and stilling basin length. To calculate the dimensions of this stilling basin, the Froude number at the upstream of the energy dissipator is required. For this purpose, an initial calculation of the Froude number must be performed with a value of 2.5 < F < 4.5, which is obtained from 6 variations of discharge and water level above the spillway. From the results of this initial calculation, a middle Froude number will then be selected to be used as the basis for calculating the dimensions of the stilling basin and designing the dimensions of the baffle block.

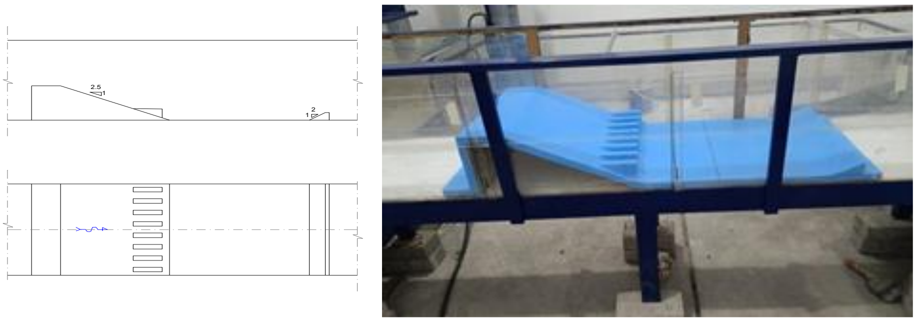


Figure 2. Model Series 0 USBR Type IV Stilling Basin

Model Construction

Model Series 1 is a modification of the Series 0 stilling basin model, which is based on the design of the USBR Type IV stilling basin with the addition of a wedge baffle block. The baffle blocks are placed downstream of the spillway foot with the placement distance based on the baffle block installation pattern in the USBR Type III stilling basin. As a reference, the dimensions of the baffle blocks are determined based on the planning of the 4th discharge variation out of the 6 discharge variations to be studied. Typical cross-sections of the baffle blocks are shown in Figures 3 and 4. The initial hypothesis is that the USBR Type IV settling pond will operate more efficiently with the addition of baffle blocks and will help reduce the oscillating jumps that occur. The efficiency of the attenuation will be studied for each flow variation.

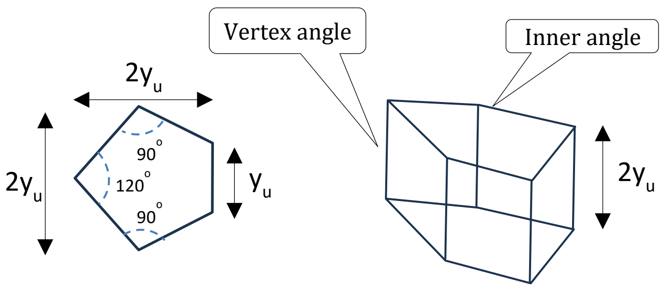


Figure 3. Wedge Type Baffle Block Model

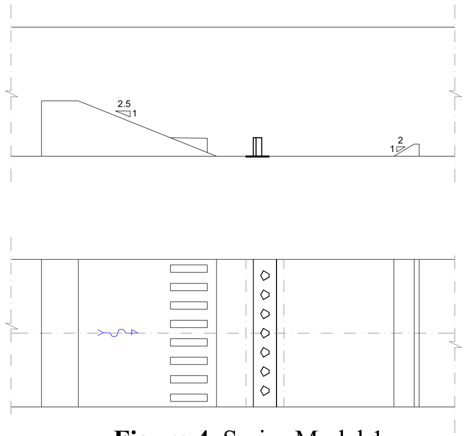
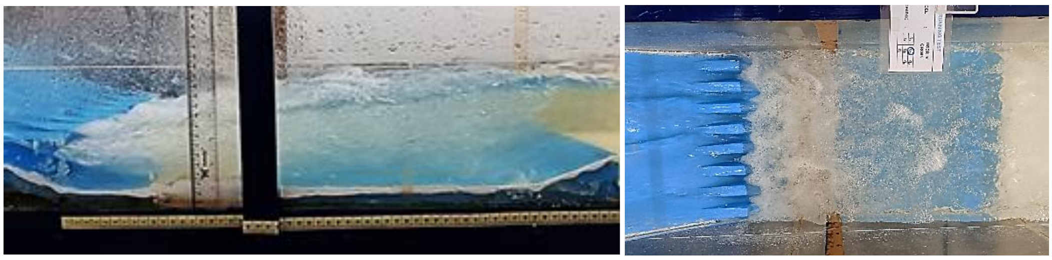


Figure 4. Series Model 1

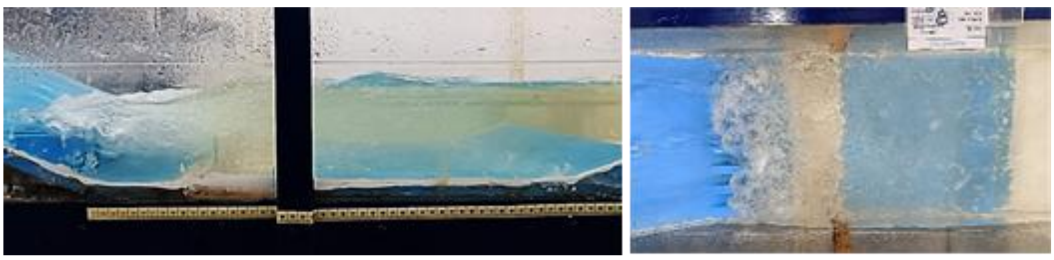
The measuring instruments used in this study consisted of a digital current meter, roll meter, and point gauge. The current meter was used to measure flow velocity, the roll meter was used to measure the length of the turbulent flow and hydraulic jump, while the point gauge was used to measure the water level at observation points. Flow discharge measurements were controlled via a rechbox on the upstream and downstream sides of the test model.

Model Simulation

Simulations were conducted on Series Model 0 and Series Model 1 by flowing 6 discharge variations over the spillway, which produced Froude numbers between 3.5 and 4.3.



a. Flow test q1 Series Model 0



b. Flow test q1 Series Model 1

Figure 5. Flow test q1 Series Model 0 and Series Model 1

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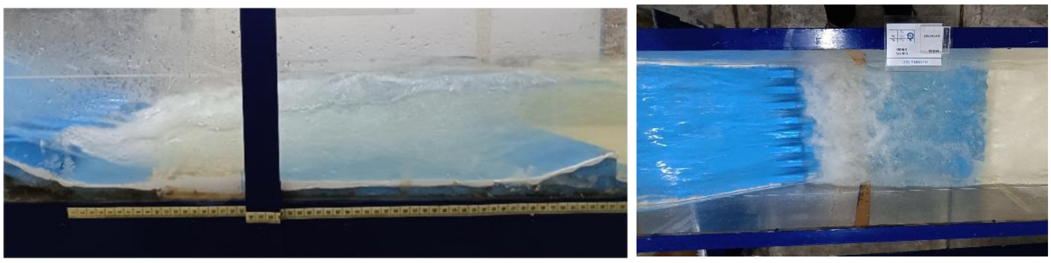
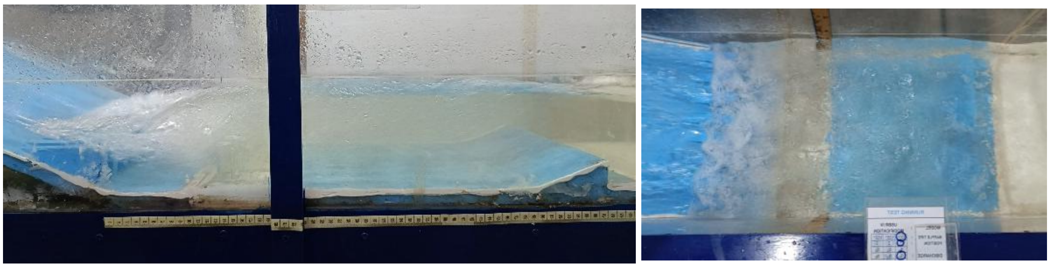


a. Flow test q4 Series Model 0



b. Flow test q4 Series Model 1

Figure 6. Flow test q3 Series Model 0 and Series Model 1

Simulation Data Analysis

The Series 0 model flow test simulation shows massive turbulent flow as a hydraulic jump from the spillway toe to near the toe threshold. This is indicated by the presence of air bubbles that are pushed far to the toe threshold. The maximum water level rise occurs at the end of the air bubble flow that travels upward and indicates the end point of the hydraulic jump. The maximum water level rise appears in contrast to the conditions of greater discharge until the water level finally decreases after passing the end threshold.

In the Series 1 model flow test simulation, there was a rise in water level between the spillway foot and the baffle block as an early sign of a hydraulic jump, ending not far downstream of the baffle block. The end of the hydraulic jump was marked by a rise in water level and a decrease in air bubble content.

This condition is clarified by the appearance of turbulence and air bubbles that appear on the water surface from the top side documentation photo. In the Series 0 Model, the appearance of turbulence and air bubbles is quite intense in the area of the spillway foot to the end threshold and still leaves a flow that flows away from the stilling basin.

In contrast, in the Series 1 Model, the appearance of turbulence and water bubbles is intense in the overflow foot and baffle block areas and gradually decreases before reaching the end threshold. The remaining overflow flowing away from the overflow pond is not too dominant.

In the Series 1 Model flow test simulation, there was a backflow phenomenon at the base of the spillway and partially above the chute block. The backflow above the chute block tended to consist of a series of bubbles that did not have destructive power.

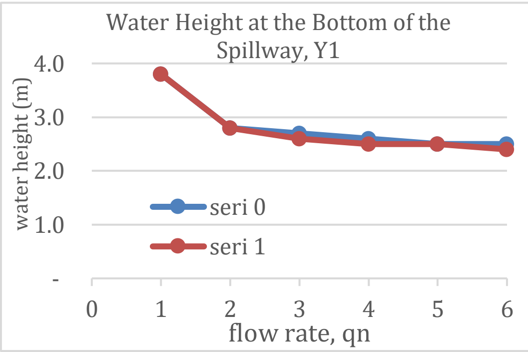
RESULTS AND DISCUSSION

In this activity, planning for the spillway and USBR Type IV stilling basin was carried out, followed by modeling design including spillway, stilling basin, baffle block, and design of planned discharge and tail water depth.

Model Series 0 is a stilling basin model based on the design of the USBR Type IV stilling basin, while Model Series 1 is a modification of the Series 0 stilling basin model based on the design of the USBR Type IV stilling basin with the addition of a wedge baffle block.

Next, test scenarios and model runs were prepared. During the model runs, measurements and recordings were taken, including: inflow and outflow discharge, flow velocity and water level upstream and downstream of the stilling basin, water jump length and height, and documentation of flow movement.

Based on the results of the physical model testing, the following data was collected:



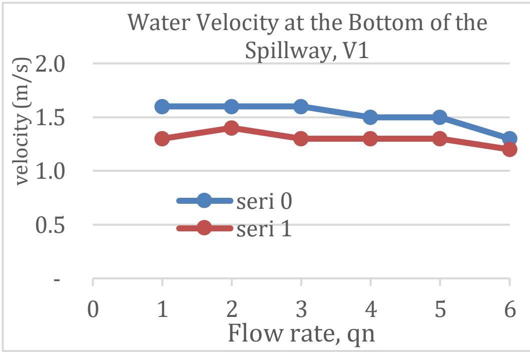


Figure 7. Water Height and Velocity at the Foot of Spillways Model Series 0 and Model Series 1

At the overflow outlet, the flow velocity in Model Series 1 was lower than in Model Series 0, indicating that the placement of the baffle block had an effect on the reduction in velocity. In terms of flow height, there was a slight difference between Model Series 1 and Model Series 0, with the flow height in Series 0 being slightly higher.

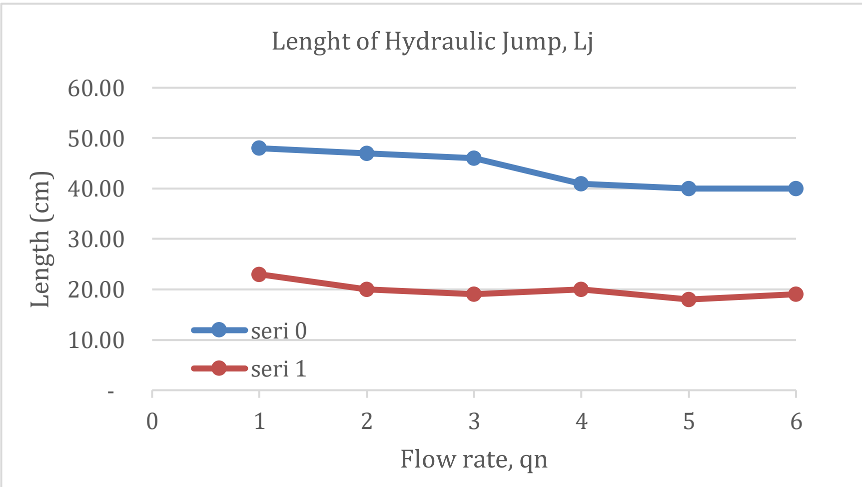


Figure 8. Length of Hydraulic Jump of Model Series 0 and Model Series 1

The jump in Series Model 0 is much longer than in Series Model 1. In general, this indicates the effectiveness of energy dissipation in Series Model 1, where the flow after the jump tends to be subcritical and the length of the return stilling basin can be shortened economically.

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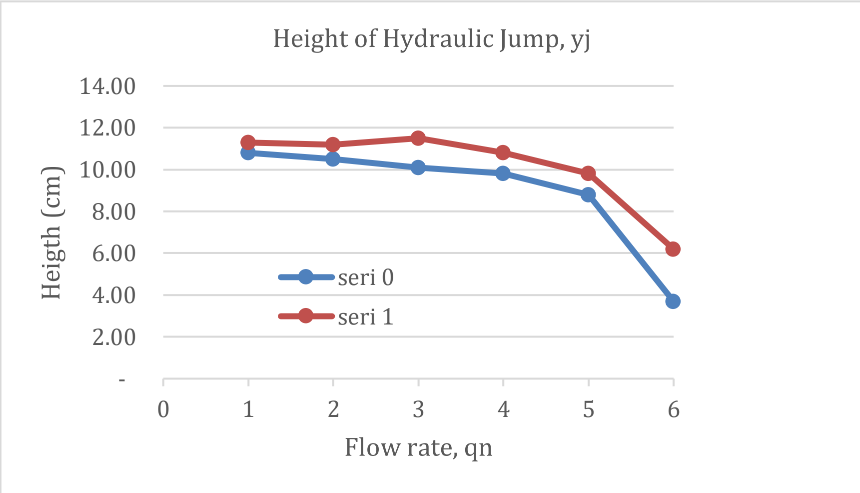

Figure 9. Height of Hydraulic Jump Model Series 0 and Model Series 1

The jump height in Series Model 1 is higher than in Series Model 0, where the greater the discharge, the greater the difference in jump height. In addition to demonstrating the effectiveness of energy dissipation in Series Model 1, the dissipation effect is also more effective at greater discharges.

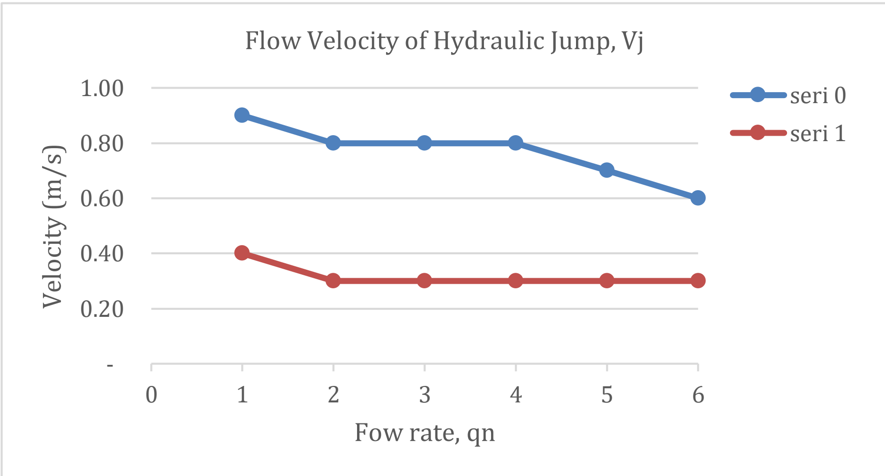

Figure 10. Flow Velocity of Series Model 0 and Series Model 1

The flow velocity in Series Model 1 is lower than in Series Model 0, where the lower the flow velocity, the more subcritical the flow becomes, reducing the destructive force of the flow on the riverbed and downstream cliffs. This increases the safety factor in the design of the retention pond.

CONCLUSION

Research on the Effect of Wedge Baffle Blocks on the USBR IV Recirculation Pond using Wedge Baffle Blocks with a 120º front angle produced the following conclusions: a) The Wedge type Baffle Block has a significant impact on the velocity and length of the hydraulic jump, b) The turbulence effect that occurs along the hydraulic jump to the end sill in the Series 0 Model is reduced when the Wedge type Baffle Block is placed in the Series 1 Model, c) There is an increase in flow height approaching the Wedge type Baffle Block and maximum flow height after passing the Wedge type Baffle Block, accompanied by a decrease in flow velocity as an indication of energy damping and a decrease in the Froude number of the flow, d) A reverse flow is formed, floating above the base flow that creeps upstream toward the spillway foot, e) At the spillway foot, the flow velocity in Model

Series 1 is lower than in Model Series 0, indicating that the placement of the baffle block affects the decrease in velocity.

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