Flow Characteristics of Stilling Basin, Case Study: Karian Dam, Central Java Province

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Abstract. The hydraulic jump is a process is to reduce most of the energy that occurs in spillway. It can also raise the water level in the lower reaches. A very large energy flow that must be reduced so as not to endanger the end of the dam's overflow channel. The dissipation structure, such as stilling basin at the end of the spillway, plays a role in reducing kinetic energy flow before the flow enters the river. This paper aims to analyse the effect of the baffle block along with the layout of the stilling bed. The experiment was comparing the stilling basin without and with a baffle block, where hydraulic jump intently occurs with variation of flow rate from \( Q_{50} \) to \( Q_{PMF} \). This research results that stilling basin with baffle block with a bucket angle of 23.33° has the most effective variation among the others compared to \( L_j \) and \( H_j \) values. \( L_j/H_1 \) and \( H_2/H_1 \) has linear relationship with Froude Number (Fr), which is the higher discharge rate, the higher \( L_j/H_1 \), \( H_2/H_1 \) and Fr value they obtain.

Keywords: Karian Dam, Energy Dissipation, Hydraulic Jump, Flip Bucket Spillway, Flow-3D

1. Introduction

Spillway is a part of the dam structure. Spillway is a main aspect for a dam. Spillway has a purpose to flush excess of the river water to the downstream of the river [1]. Spillway is a part of flow control structure, that makes water level arise. Then, the water will flow through the spillway. Due the water level arise, it will changes the water movement and energy rapidly. Before the water comes through the spillway, water flow is in natural condition. But, after water pass through the spillway it began changes of velocity (in supercritical state). Those flow must be decrease and change to the subcritical state, after water velocity reduce to it subcritical state then water will not create erosion to the downstream canal and stabilize the way of downstream river. To reduce energy from the water flow, added some effective dissipation energy structure on the downstream canal to protect spillway structure from the scour[2].

Dissipation energy structure also known as Stilling Basin are the common use to dissipate water energy [3]. Although stilling basin and dissipation energy material are designed together with spillway, outlet and canal structure it also need individual model design review to check every structure are in optimal condition to operate. The reason to review every structure is a uncertainty factor about
performance characteristic of dissipation energy structure. Many research are done for individual structure in years with different researcher for group of designer, every structure has different boundary condition [4,5,6]. Because, not every single structure are the same, the effort to generalize data collecting and the result was blurry images. Sometimes, the result are inconsistent, it has unknown connection link.

Therefore it is important to fulfill needs of information about new hydraulic design and energy dissipation structure. The aim of this study is to analyze energy dissipation structure of stilling basin at Krisak dam, located in Central Java Province. Previous study in Krisak dam [7] supported the data collection process in this research. An outcome of this study will bring an update to the simple aspect for designing stilling basin structure.

2. Methodology

2.1. Baffle Block Design Parameter

Energy dissipation structure begin with designed shape and parameter of the energy dissipation structure [8]. In this study, the energy dissipation structure shape is using trapezoid shape [9]. The parameter consist of \( V_T \) = theoretical velocity (m/s), actual velocity \( (V_A) \), \( D_1 \) = water depth before hydraulic jump, \( Fr \) = Froude number, and \( D_2 \) = water depth before hydraulic jump (Table 1). Figure 1 is a baffle block design that used on this research. Shape of baffle block is trapezoid shape. Based on Table 1, dimension of baffle block can be obtained as follows (Table 2).

| Parameter  | Result |
|------------|--------|
| \( V_T \) (m/s)  | 30.51  |
| \( V_A \) (m/s)  | 28.99  |
| \( D_1 \) (m)    | 2.72   |
| \( Fr \)        | 5.62   |
| \( D_2 \) (m)    | 20.389 |

![Figure 1. Baffle block design](image)

| Description | Dimension (m) |
|-------------|---------------|
| h           | 4.35          |
| a           | 0.87          |
| b           | 5.22          |
| w           | 3.26          |
2.2. Designing Layout Modelling

Spillway model is built by AutoCAD 3D (Figure 2) with existing condition (Karian Dam) also same dimension between model and existing condition. The layout is using the arrangement of A3 with flip bucket of 23.33° angle (Figure 3-4). Then, compare variation models and existing condition to determine the effective models. The baffled model is influenced to the flow pattern.

![Figure 2. Layout of Karian dam spillway](image2)

![Figure 3. Angle of flip bucket (red dotted circle)](image3)

![Figure 4. Layout A3](image4)

2.3. Numerical Analysis (CFD)

CFD method is defined as a solution with numerical algorithm from the hydrodynamics flow problem [10,11,12]. In general, CFD is a method that use to analysis every kind of fluid and flow in different condition. In this method, there are 3 governing equations (continuity, momentum and specific energy) which are basic principal equations and applied from the pressure, velocity, temperature distribution and many more approach depends on other parameter or data to solve numerically [13]. Momentum equation is a general equation of moving fluid for fluid velocity component \((u, v, w)\) on 3 coordinate direction:

\[
\frac{\partial u}{\partial t} + \frac{1}{V_F} \left( u A_x \frac{\partial u}{\partial x} + v A_y \frac{\partial u}{\partial y} + w A_z \frac{\partial u}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial P}{\partial x} + G_x + f_x
\]  

(1)

\[
\frac{\partial u}{\partial t} + \frac{1}{V_F} \left( u A_x \frac{\partial v}{\partial x} + v A_y \frac{\partial v}{\partial y} + w A_z \frac{\partial v}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial P}{\partial y} + G_y + f_y
\]  

(2)

\[
\frac{\partial u}{\partial t} + \frac{1}{V_F} \left( u A_x \frac{\partial w}{\partial x} + v A_y \frac{\partial w}{\partial y} + w A_z \frac{\partial w}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial P}{\partial z} + G_z + f_z
\]  

(3)
Inside that equations there is P variable also known fluid pressure, while variable (Gx, Gy, Gz) is a value from body accelerations that form because of flow of fluid acceleration, and (fx, fy, fz) is a viscosity acceleration [14].

3. Results and Discussion

Angle of 30° is the existing condition, without baffle block, which is refer to the Karian Dam condition, while angle of 23.33° is the flip bucket applied on this research (Figures 5-6). From the calculation result (Tables 3-4) reveal that the increases of flow discharge are proportional to the velocity, water elevation, length of jump and Froude Number. Initial velocity (V1) is relatively bigger, while end velocity (V2) is smaller because the water flow through the flip bucket and become hydraulic jump. Height of jump is depending to the angle of flip bucket and water discharge.

![Figure 5. Measuring Points](image1)

| Bucket Angle (°) | Q (m³/sec) | H1 | H2 | A1 | A2 | V1 | V2 | Fr1 | Fr2 | Lj | Lj/H1 | H2/H1 |
|-----------------|------------|----|----|----|----|----|----|-----|-----|----|-------|-------|
| No Baffle 30    | 185        | 2.030 | 5,510 | 50,750 | 196,490 | 3,465 | 0.942 | 0.817 | 0.128 | 20,880 | 10,286 | 2,714 |
|                 | 266        | 2.170 | 6,030 | 54,250 | 231,280 | 4,903 | 1.150 | 1.063 | 0.150 | 23,160 | 10,673 | 2,779 |
|                 | 534        | 2.230 | 6,840 | 55,750 | 240,590 | 9,578 | 2.220 | 2.048 | 0.271 | 27,660 | 12,404 | 3,067 |

![Figure 6. Measuring Points](image2)

| Layout A3 with Baffle 23,33 | Q (m³/sec) | H1 | H2 | A1 | A2 | V1 | V2 | Fr1 | Fr2 | Lj | Lj/H1 | H2/H1 |
|------------------------------|------------|----|----|----|----|----|----|-----|-----|----|-------|-------|
| 185                          | 2.030      | 3,540 | 50,750 | 265,145 | 3,645 | 0.698 | 0.817 | 0.118 | 20,498 | 10,976 | 1,744 |
| 266                          | 2.170      | 4,020 | 54,250 | 286,813 | 4,903 | 0.927 | 1.063 | 0.148 | 23,053 | 10,623 | 1,853 |
| 534                          | 2.230      | 4,850 | 55,750 | 293,171 | 9,578 | 1.821 | 2.048 | 0.264 | 26,957 | 12,088 | 2,175 |

![Table 3. Result of Theoretical method](image3)

![Table 4. Results of Numerical Method (CFD)](image4)
Table 5. Results of Froude Number with Numerical Method (CFD)

| Bucket Angle (°) | Q (m³/sec) | Froude Number |
|------------------|------------|---------------|
|                  | point 1    | point 2       | point 3    | point 4    | point 5    |
| No Baffle        | 30         | 185           | 4,952      | 2,142      | 1,993      | 0,642      |
|                  | 266        | 1,492         | 5,078      | 2,307      | 2,019      | 0,725      |
|                  | 534        | 1,930         | 5,257      | 2,333      | 2,107      | 0,778      |
|                  | 3190       | 1,654         | 5,435      | 2,412      | 2,133      | 0,861      |
| Layout A3 with Baffle | 23,33 | 185           | 1,448      | 5,022      | 2,722      | 1,435      | 0,444      |
|                  | 266        | 1,495         | 5,119      | 2,777      | 1,498      | 0,601      |
|                  | 534        | 1,934         | 5,292      | 2,815      | 1,591      | 0,728      |
|                  | 3190       | 1,647         | 5,485      | 2,708      | 1,596      | 0,880      |

Froude Number shows the characteristic that flow through the spillway (Table 5). Point 2 reveal the flow pattern is tend to supercritical state, caused by change of channel elevation that flow to the downstream and rapidly increase water velocity. At point 3, Froude Number already reduce because water has jump. Point 4 shows the water getting slow and gentle caused by the water flow through the baffle block (especially layout with addition of baffle block).

3.1. Impact of Baffle Block Against Change of Flow Characteristic on Stilling Basin

The following is the result of flow characteristic with comparison of Lj/H1 and Froude Number:

![Figure 7. Comparison Lj/H1 with Froude Number without Baffle Block](image1)

![Figure 8. Comparison Lj/H1 with Froude Number (Layout A3)](image2)

The lower angle of flip bucket then the Froude Number will increase and smaller Lj/H1 (Figure 7 and 8). However, if angle of flip bucket raises then the Froude number decrease and higher Lj/H1. For example, layout A3 has Froude Number 5.49 with comparison parameter Lj/H1 equal to 22.29.

The following is the result of flow characteristic with comparison of H2/H1 and Froude Number: Result of comparison graph H2/H1 with Froude Number (Figure 9 and 10) reveal that effect of energy dissipation structure (baffle block) is reducing the Froude Number. That matter is based on variation of stilling basin model.
3.2. Analysis of Flow Characteristic

Based on numerical method compare to the other research it will result the flow characteristic with same parameters and variation. Other research that compares with this research is based on [15] and [16]. That researcher using type of spillway of Ogee spillway with addition of baffle block as energy dissipator. Analysis parameter using non dimensional parameter of Lj/H1 and H2/H1. The following is comparison graph with other research

From Figure 11 and 12, it reveals that the result has an uptrend from other research and layout A3. That trend shows flow condition if flow discharge increase then the Froude Number increase. That condition is fulfilled if using the parameter Lj/H1 and H2/H1 which is the area of measure

4. Conclusion

Impact of water flow that entering the spillway is influenced by the water flow velocity. Velocity on existing condition at Karian Dam before hydraulic jump (V1) is equal to 28.23 m/s and velocity after hydraulic jump (V2) is equal to 16.02 m/s. In other word, the water condition before hydraulic jump is supercritical state change into subcritical state after hydraulic jump. Layout variation has effective layout that is A3 with angle 23.33° with length of jump (Lj) difference 14.36 than existing condition (Karian Dam) and difference of height jump is equal to 3.01. Lj/H1 and H2/H1 is non-dimensional parameter that compared to Froude Number came with result, that comparison
parameter has single uptrend. It means, increases of flow discharge is increase Froude Number and Non-dimensional parameter (Lj/H1 and H2/H1).

For further study, it is suggested that comparison should be conducted with more variation of baffle block shape because changing baffle block shape will help in increasing dissipation rate and relocating baffle block locations.

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