The results obtained according to the studies carried out shows that the energy-dissipating rates were all design are different. Hydraulic jump occurred in all experimental setups. Experimental study results and numerical model results had almost the same values.

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O 54. THE EFFECT OF LAYOUT OF ENERGY DISSIPATORS ON ENERGY DISSIPATE

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ABSTRACT: Energy dissipater in the stilling basin is a structure designed to protect downstream of the spillway from erosion and scour by reducing flow energy in the energy dissipation pool. Energy dissipation pool is an important element of hydraulic structures as a transition between the high-velocity flow and the sensitive tail water. The aim of this study is to investigate the energy dissipation ratios of baffle blocks which constructed in Type III stilling basin by using physical and numerical modeling methods. Energy dissipation ratio of the baffle blocks were determined in 3 different layouts as single row, two rows and two rows without end sill are tested. In addition, these experimental studies were tested by numerical study.

Keywords: Open channel hydraulics, Spillway structures, Stilling basins, Energy dissipation block, Energy dissipaters, FLOW-3D, Hydraulic Jump.

1. INTRODUCTION

Spillways are the hydraulic structures that transfer the excessive water safely from reservoir to downstream side without damaging the dam body. A spillway structure generally consists of the approach channel, spillway, aerators and the energy dissipation structure. Approach flow discharging from top of the dam body with high energy can damage the structures on the downstream side of the spillway and by scouring. Energy dissipating structures, reduce the energy of the flow which is coming over the dam body and allow it to pass to the downstream side with lower energy. The basic principle of energy-dissipating structures is to ensure that the hydraulic jump, that formed when flow regime changes from supercritical to subcritical, occurs in the stilling basins (Hager, 1992)

Stilling basins types were first described in by Bradley and Peterka in 1957 and a series of experiments on chute blocks, baffle blocks and end sill were carried out and stilling basins types were classified according to Froude number and flow velocity. Energetic blocks are placed in the scattering pool to allow hydraulic splashing to occur and to increase turbulence. Baffle blocks are placed in the basin to allow hydraulic jump to occur and to increase turbulence, by this way needed basin length is shortening to break energy of flow. Baffle blocks can be used in a single row or in more than one row. It has been suggested by the Peterka (1984) that baffle blocks in the second and subsequent rows should be placed in a staggered manner, the first block should be placed half the width of the block from the wall, and the width of the blocks in the same row and the distance between the blocks should be equal. Some researchers have tried to increase the efficiency by changing baffle and chute block geometries in the stilling basin structure (Pagliara and Palermo, 2012; Bestawy, 2013). Cook (2002) created a numerical model of the spillway and stilling basin constructed within the scope of the Dalles project using Flow-3D and compared the results obtained from the numerical model and the physical model. Amorim (2015) compared the results obtained from numerical model of the stilling basin of the Porto Colombia Hydroelectric power plant with 1/100 scale physical model of the power plant. Nigam et al. (2016) did an overview and worked on hydraulic jump type stilling basins. They dealed with the hydrodynamic design aspect of jump type energy dissipaters by experimentally and analytically along with comparison of various energy dissipaters. Based on the estimating the uplift and hydrodynamic forces on energy dissipaters, although jump type energy dissipators with only one end sill is sufficient for higher velocities, it was not recommended to use it for head above 100 meter. Dermawan et al. (2021) was carried out the physical model study by experimentally by bottom lowering of horizontal and USBR II stilling basin. It was expected to represent flow behavior in the overflow system regarding flow conditions and energy dissipation. After experiments, the amount of flow energy that occurs at each control point is calculated. USBR II is found that, In which has baffle blocs at the toe and end sill, the flow becomes more turbulent with compared to the flat stilling basin that does not have baffle blocks.

USBR II it was better than flat stilling basin while discharge is increasing with a higher difference in overflow height.

Flow conditions on overflow systems can result in construction failure, mainly due to the high flow energy. Since the dams require a unique design (site-specific) in topographic conditions, there may be situations where the energy dissipation pool is not sufficient. In such cases, USBR designs may not be enough and additionally energy dissipater blocks can be used to obtain higher energy loss (Kumcu and Kökpınar, 2019).

In this study, the physical hydraulic model test was carried out to increase energy dissipating ratios of various baffle blocks placed in various layouts on USBR III energy dissipating pools. So, the contribution of the baffle blocks in stilling basins located downstream of the ogee spillway to find out energy dissipation ratios which were investigated by physical and numerical modeling methods.

2. MATERIAL and METHOD

A hydraulic jump is a sudden rise in the water surface that occurs when the flow regime changes from the supercritical to the subcritical. During the hydraulic jump, a significant amount of energy is absorbed over a short distance. In Figure 1 the general view of the stilling basin and hydraulic jump formed in the pool are given.

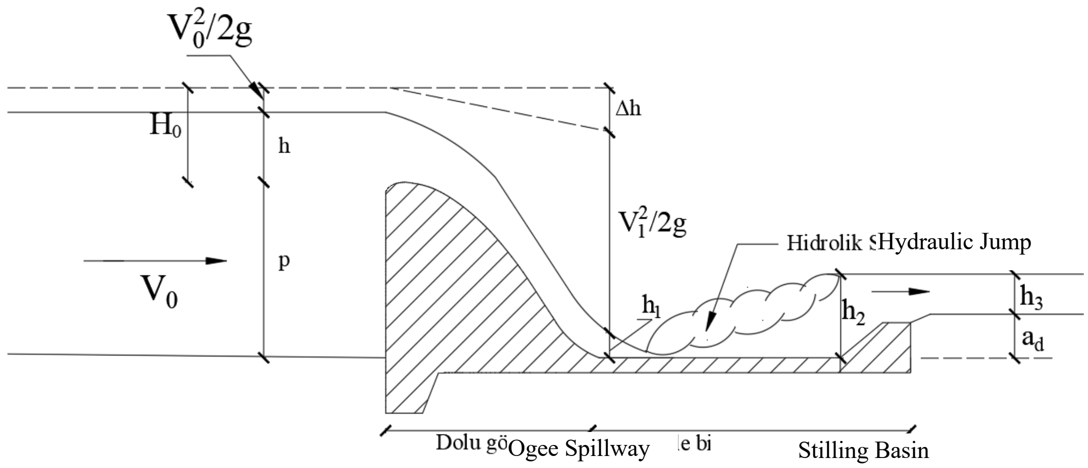


Figure 1. Hydraulic jump in the stilling basin

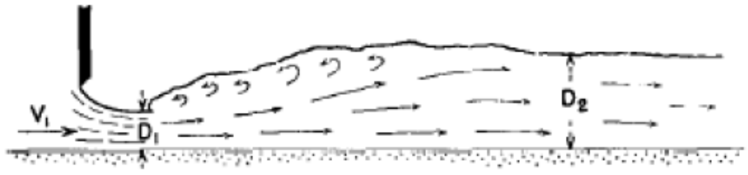
The definitions of the parameters described in Figure 1 are given below.

h_1 = Flow depth before the hydraulic jump
h_2 = Flow depth after the hydraulic jump
h_3 = Flow depth at downstream
h = Flow head over the crest
p = Crest height
a_d = End sill height
$V^2/2g$ = Velocity head
V_0 = Approach flow velocity
V_1 =Velocity of the flow before the jump
Δh= Head of the dissipated energy
H_0= Total water head over the crest

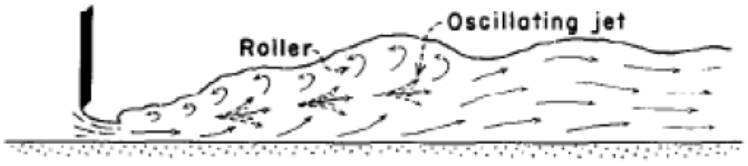
The relationship between h_1 and h_2 by using the momentum equations during the hydraulic jump is as follows.

$$\frac{h_2}{h_1} = \frac{\sqrt{1+8Fr^2}-1}{2}$$

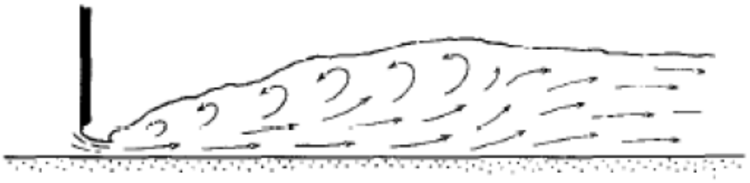
Hydraulic jumps are classified according to the Froude number as $Fr = \frac{V}{\sqrt{g \times h_1}}$. Depending on the Froude number, jump types are given in Figure 2.



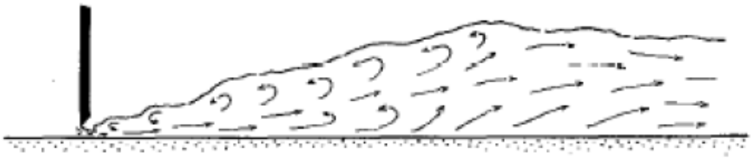
1.7< Fr < 2.5 Pre jump stage



2.5< Fr < 4.5 Transition jump



4.5 < Fr < 9; balanced jump



Fr > 9; Effective jump

Figure 2. Hydraulic jump types depending on Froude number (Peterka, 1984).

2.1. Stilling basin

Flow depth (h_1) and corresponding velocity (V_1) and Froude number (Fr) before the hydraulic jump were calculated, and the highest velocity and the Froude number were computed as 2.75 m/s and 8.83, respectively. Type III stilling basin is used when the Froude number is greater than 4.5 and the flow velocity is less than 18.3 m/s (60 ft/s). Thus, USBR type III stilling basin was chosen, which is suitable for the design in flow conditions where the calculated Froude number, Fr=8.33 is greater than 4.5 and the maximum velocity V_1=2,75 is less than 18.3 m/s (60 ft/s). Type III stilling basin is designed according to USBR and dimensioning of the basin, baffle and chute blocks are given in Figure . Limit values of the study are given in Table 1.

Table 1. Max and Min values used for designing USBR Type III basin

Min / Max	Q (l/s)	H (cm)	h_1 (cm)	Channel width, B (cm)	V=Q/A (m/s)	$F_r = V/\sqrt{gh_1}$	$\frac{h_2}{h_1} = \frac{\sqrt{1+8Fr^2}-1}{2}$
Min	1.10	1.52	0.26	30.00	1.41	8.83	3.12
Max	39.62	14.40	4.80	30.00	2.75	4.01	24.92

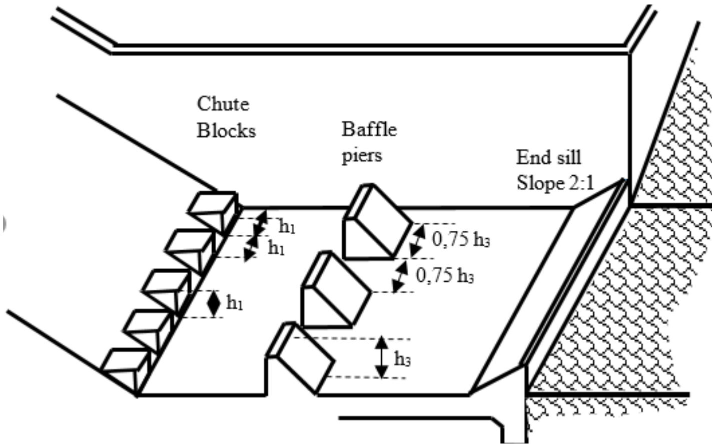


Figure 3. Type III stilling basin (Peterka, 1984)

2.2. Experimental setup

Experiments were carried out in a rectangular open channel with a length of 670 cm, a width of 30 cm and a depth of 50 cm. In the experimental setup, flow in the open channel is provided by two pumps, each of which has a power of 7.5 kW, connected in parallel to the system. The water flowing in the open channel system is supplied from two reservoirs. The pumps take the water from the reservoir-1 and convey it into reservoir-2. Then, the water reaches to the reservoir-2 passes through the laboratory flume and is poured back into the reservoir -1 (**Error! Reference source not found.**). The total discharge in the channel is equal to the sum of the flows supplied from both pumps. The flow discharge that the pumps will provide is adjusted by the frequency alternative on the panel to which the pumps are connected The flow through the system is read by electromagnetic flowmeter placed between the pipes after the pumps Flow depth was measured with a limnimeter with an accuracy of ±1 mm placed in the open channel (**Error! Reference source not found.**). The open channel flume is made of 1.2 cm thick laminated glass-walled, which is obtained by combining two 0.6 cm thick tempered glass sheets with a plastic layer placed between them. In the experiments, ogee type profile and stilling basin made of plexiglas.

Experiments are conducted for 7 various discharge values (10, 15, 20, 25, 30, 35 and 39.62 l/s). Stilling basin elements were prepared in accordance with the methods recommended by the USBR and adhered to the open channel with the help of silicone. The flow depths were measured with the help of a limnimeter.

2.3. The Effect of the Shape of Energy Dissipater Blocks on Energy Dissipation

Experimental studies were carried out on physical models for investigating the energy absorption ratios of the energy dissipating blocks placed in the USBR Type III stilling basin. In the experiments, the data obtained by measuring the height after splashing and downstream water level at 7 different flow rates were compared, and the energy dissipating ratios were calculated. In the experiments, trapezoidal energy dissipater were used. The energy block types used were placed in the energy dissipating pool first in a single row, then 2 rows and then 2 rows without threshold, and the flow conditions were investigated. Plan and profile views of the energy dissipating block types are given in **Error! Reference source not found.**.

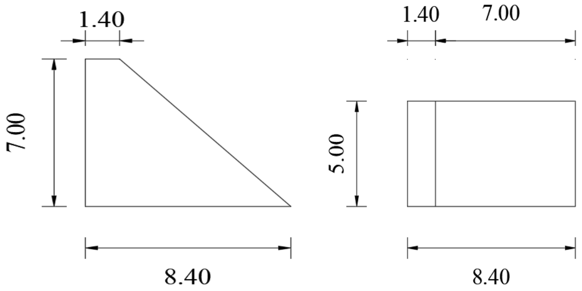


Figure 4. Block types used in the experiments; a) Longitudinal cross-section and b) Top view of the dissipating block types

2.4. Numerical Modelling

FLOW-3D is a computational fluid dynamics solver, a commercial mathematical computation program that can solve multiple fluid mixtures using the finite difference method. A single fluid-free surface flow solution was used in the analyses. For the VOF (Volume of fluid) method, it is provided to define the fill or void ratio of each mesh cell and to perform pre-debugging by using pre-process. Mesh cells of 5 mm size were used in the analyses, and the mesh block contains a total of 1,536.000 cells. The part where water enters the system (-X side) is defined as the pressure (static water level). Depending on the desired weir load on the weir, the height of this static water level was adjusted and water was allowed to enter at the desired height. The side surfaces and the bottom of the pool were chosen as walls, the downstream part as outflow and the upper part as pressure to represent the atmospheric pressure. To obtain the desired analysis results, Fluid Fraction (filling ratio) and hydraulic data options are marked in the "output" section. The solid model and layer conditions used in the analysis are shown in Figure 5.

The velocity and Froude number values calculated by numerical model are shown in **Error! Reference source not found.**. According to the numerical model, the maximum Froude number was calculated as 7.25 and the maximum velocity was calculated as 3.06. These values are consistent with the values chosen during the selection and design of the energy dissipating structure and show the accuracy of the numerical model.

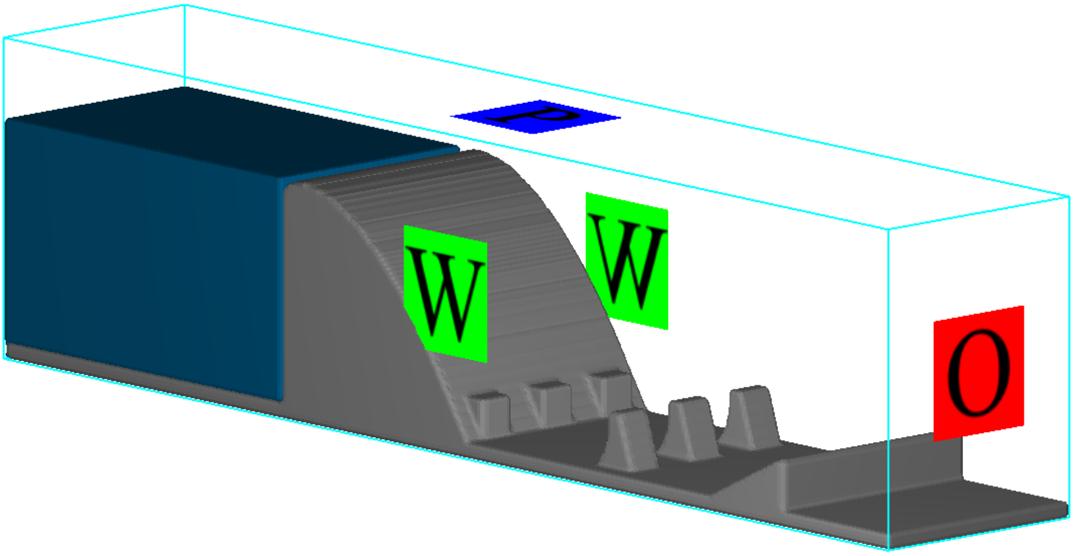


Figure 5. Solid model used in the CFD simulations of single row trapezoidal energy dissipaters

3. RESULTS and DISCUSSION

3.1. Physical Model

During this experimental study on the open channel, the energy dissipation ratios of baffle blocks having different geometric shapes were investigated with the help of the hydraulic jump created in the flow. The measured depths and velocities of the flow before and after the hydraulic jump formation were investigated, and the energy dissipation ratios were found by computing the total heads of the flow. To determine the amount of energy dissipation and to find the most effective plan shape of baffle blocks were designed as; single row, double row and double rows and compared according to their non-threshold arrangement. The graphs is given in Figure .

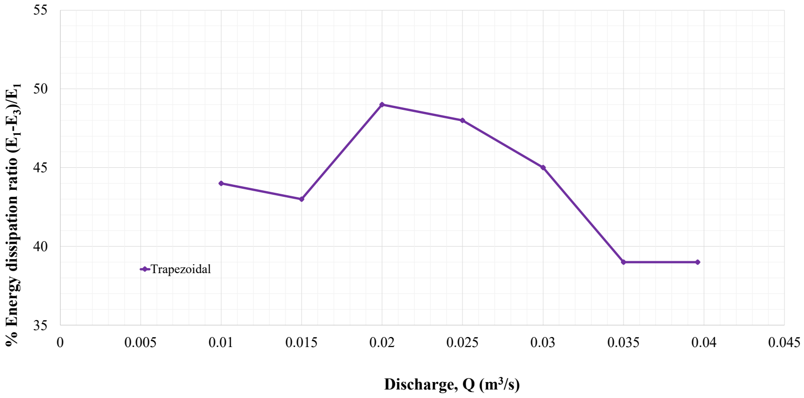


Figure 6. Energy dissipating rations of the single row energy dissipaters

When the energy dissipation ratios of the single row energy dissipater blocks are examined in Figure 7, it is seen that the highest absorption rate is obtained at 20 l/s, which corresponds to almost 50% of the total head of the flow.

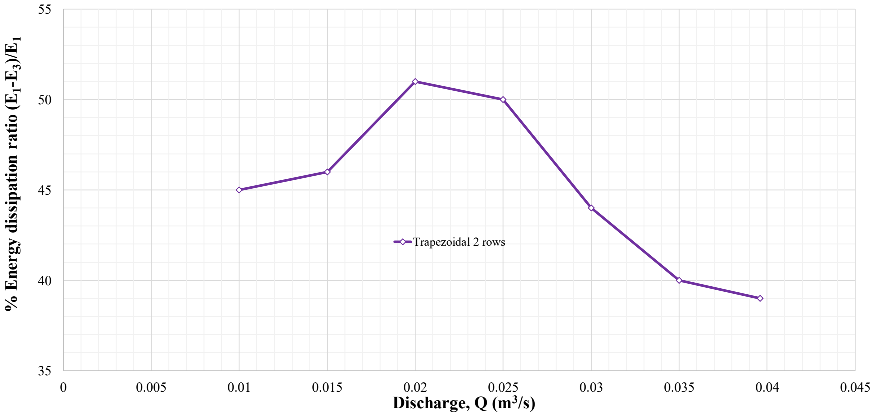


Figure 7. Energy dissipating rations of two rows energy dissipaters

When the energy damping ratios of the two-row energy breaker blocks are examined in Figure 8, it is seen that the highest damping rate decreased by 51% with 20 l/s, which corresponds to almost 50% of the design flow. In the design flow, it was observed that the highest energy breaking rate belonged to the T-section energy breaker block plan and reached 39%.

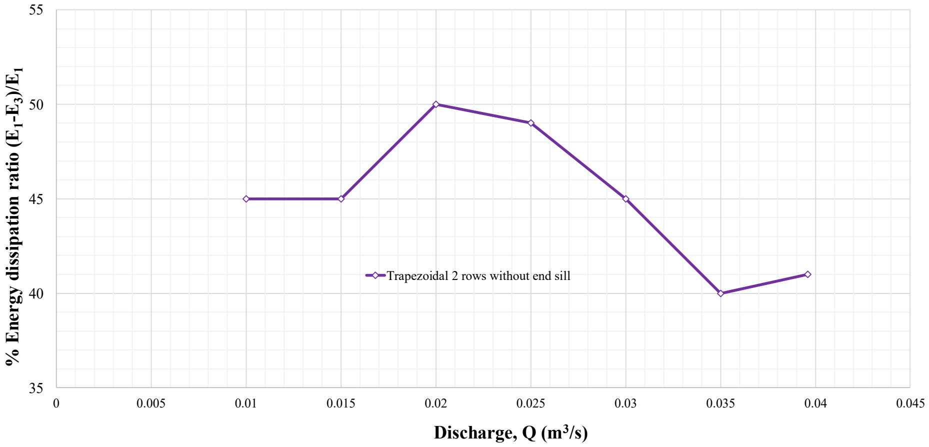


Figure 8. Energy dissipating rations of the two rows without end sill energy dissipaters

When the energy dissipation ratios of the two rows of without end sill energy dissipation blocks are examined in Figure 15, it is seen that the highest energy dissipating rate is reduced by 51% with 20 l/s, which corresponds to almost 50% of the design flow.

3.2. Mathematical Modelling

The experimental setups of the single row energy reduction blocks used in the experimental study were tested with the FLOW-3D mathematical method at the design flow rate, and the data on the hydraulic properties obtained are given in

Table **2**. When this table is analyzed, the energy breaking blocks with Trapezoidal cross-sections have energy breaking percentages is almost 39%.

Table 2. The results of mathematical modelling of the single row energy dissipating block

Type	h_1 (m)	V_1(m/s)	E_1 (m)	h_3 (m)	V_3 (m/s)	E_3 (m)	$(E_1$-$E_3)/E_1$	Fr_1	Fr_2
Trapezoidal	0,0480	2,75	0,4338	0,2495	0,53	0,2638	0,39	4,01	0,34

3.3. Comparison of Physical and Mathematical Model Results

Experimental setups of single row energy breaker blocks were tested physically at seven different flow rates and with the FLOW-3D mathematical method at the design flow. When the energy dissipation rates of the energy dissipating blocks are analyzed in Table 3, the experimental study results and the FLOW-3D results have almost the same values.

Table 3. Energy reducing rates obtained by mathematical modelling for the single row energy dissipating block at design discharge

	Physical modelling			Mathematical Modelling		
Block	h_3 (m)	V_3 (m/s)	$(E_1$-$E_3)/E_1$	h_3 (m)	V_3 (m/s)	$(E_1$-$E_3)/E_1$
Type	0,2485	0,53	0,39	0,2495	0,53	0,39
Trapezoidal	0,2515	0,53	0,39	0,2500	0,53	0,39

4. CONCLUSIONS

A series of experiments were carried out to investigate the similarities and differences of the dissipating ratios of the different layout of energy dissipating blocks placed in the USBR Type III energy dissipating pool, the experimental study and the mathematical model.