



## Utilizing of using blocks in the stilling basin and their effects on characteristics of the hydraulic jump

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### Abstract

The stilling basin is a frequently used energy dissipators that converts supercritical flow from a dam's spillway into subcritical flow that is in compatible with the downstream river regime. They serve to prevent scouring, which happens when high-velocity water enters the dam's downstream reach. This scouring not only seriously erodes the downstream area but also damages the dam's foundation. In this research, the behavior of blocks of stilling basin and spillway toe in reducing energy losses and the longitudinal hydraulic jump toe position is evaluated. This research includes two cases ; case1 is a spillway and stilling basin without blocks, and case2 which is a spillway and stilling basin with chute blocks and middle blocks. By increasing the discharge from 0.010 m<sup>3</sup>/s to 0.020 m<sup>3</sup>/s, the difference in the dissipation energy for case1 and case2 are (17.6%, 24.7%) respectively, and that the percentage of decrease in the longitudinal hydraulic jump toe position is (83.94%, 85.90%, 86.30%, 87.20%, 88.39%, 87.58%, 80.64%, 77.94%) for the discharges tests from ( 0.010 m<sup>3</sup>/s to 0.017 m<sup>3</sup>/s). As a results, The using of blocks in stilling basin and spillway led to a rise in relative energy dissipation and decrease the longitudinal hydraulic jump toe position of stilling basins.

**Keywords:** *Spillway, Stilling Basin, Energy Dissipater, Hydraulic Jump.*

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### 1. Introduction

One of the challenges that arises following the construction of dam weirs and diversion dams is the hydraulic jump and its stability inside the stilling basin. There are usually phenomena like erosion of the river bed after the stilling basin, scour holes, and transfer of hydraulic jump to the downstream causing damage in large dams and diversion dams through which the flood flow passes. Building blocks in the supercritical flow area is one way to stabilize the hydraulic jump and lower the energy of the flow when it enters the river. Fig. 1 shows an indication of a stilling basin. Tests were carried out on a hydraulic jump properties and energy dissipation located downstream gate in rectangular channel, and discovered a connection between hydraulic jump energy dissipation and a function of Weber Numbers, Froude, and gate opening. Bhowmik [1] made laboratory tests to show the possibilities to increase energy loss and to shorten the required basins length to a particular range for Froude Number of 2.5 to 4.5. Eloubaidy [2] studied an experimental study with respect to the effects of curvature, relative size, and location of curved baffle block for the energy dissipation and controls hydraulic jump. Hayawi [3] carried out a hydraulic jump

properties and energy dissipation located downstream gate in rectangular channel. They discovered a connection between hydraulic jump energy dissipation and a function of Weber Numbers, Froude, and gate opening. Ashraf [4] made laboratory study with respect to the hydraulic jump properties related to an artificially roughened bed that have wedge-shaped baffle blocks. New experimental formula were developed for determining the sequent depth ratio and the hydraulic jump length in terms of the inflow Froude number and relative bed roughness. Christopher [5] carried out a chute spillway with baffle blocks. The design process is empirical and gives the designer a variety of baffle heights, practical arrangements, and baffle spacing. Rasoul [6] studied the effect of bed-block roughness in an ogee spillway on the energy dissipation, and investigated the jet length. Using an ogee spillway with block roughness situated on the bed without a flip bucket and with a flip bucket at different take-off angles.

The present research conducts experimental analysis on utilizing of using blocks and middle blocks in the stilling basin and their effects on the characteristics of the hydraulic jump considering the amount of dynamic energy dissipation of water and longitudinal hydraulic jump toe position. Experiments were performed on physical models

in an ogee spillway (USBR alternative Type IV) with and without blocks at a different range of Froude numbers.



Figure 1. An indication on a stilling basin

## 2. Materials and methods

Due to the complex behavior of flow over the USBR stilling basin caused by the interactions between the entrapped air and turbulent flow. These interactions are not fully understood [7]. Physical modeling is the method for predicting the hydraulic properties of stilling basin. Hence, in this research, the physical modeling was selected and laboratory work was performed to study using blocks in the stilling basin and their effect on characteristics of the hydraulic jump.

### 2.1 Flume and Instruments

The tests were conducted in a recirculating flume located at the fluid laboratory of Engineering College, Babylon University Fig. 2. The flume is 10 m length, 30 cm width, and side walls with height of 45 cm. This flume has a pump with a discharge capacity of 20 l/s. To eliminate turbulence in the entrance region, a screen plate was added at the inlet of the flume. In addition, the spillway models were installed at 2.5 m downstream of the inlet tank where flow slowly entered the laboratory flume to ensure steady flow. A flow meter is installed on its pipeline and calibrated for measuring the discharge of the passing flow. Three sensors for water level measuring were mounted on brass rail at the top of flume sides, which have an accuracy of 1 mm.



Figure 2. The used flume (Civil Engineering Department, Engineering College, Babylon University)

### 2.2 Design equations

The limitation of design model are (30 cm width, and discharges between 10 l/s to 20 l/s), and depending on dimensions of the flume

in laboratory. A spillway was designed for that discharges in order to obtain a hydraulic jump. The discharge over an ogee crest is given by the equation below [8] :

$$Q = C_d L h_e^{1.5} \quad \dots(1)$$

where: Q is a discharge in m<sup>3</sup>/s, C<sub>d</sub> is a discharge coefficient equal to 2.183, L is an effective length of crest equal to 0.30 m , and h<sub>e</sub> is an actual head being considered on the crest in m. (Q) , (L), and (C<sub>d</sub>) values were used to calculate (h<sub>e</sub>).

### 2.3 Laboratory models description

Laboratory work includes making modified models for the stilling basin alternative type IV based on the dimensions of the energy dissipators of this type. In this research, two laboratory models were made to represent two cases in the test procedure; namely case1 (spillway and stilling basin without blocks) and case2 (spillway and stilling basin with chute blocks and middle blocks) as shown in Fig. 3. These models were made from wood and coated with varnish and epoxy to increase its smoothness and to avoid wood swelling of water. This model will be made by a modified ones and not be made of the same materials as the prototype. If surfaces over which the water flows are reproduced in shape, and the roughness of the surfaces is approximately to scale (normally should be smoother in the model than in the prototype), the model will usually be satisfactory [8]. Therefore, an ogee spillway has dimensions (30 cm in width, 20 cm in height, 26.9 cm in length) in the two laboratory models. Seven chute blocks and six middle blocks were used in case2. Middle blocks installed on stilling basin base at 11 cm from the end of spillway toe. All details of laboratory models elements are presented in Fig. 4.

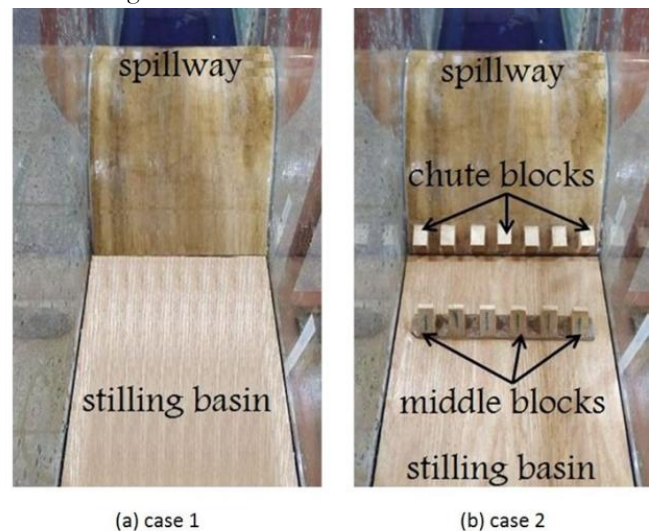


Figure 3. Cases of spillway and stilling basins

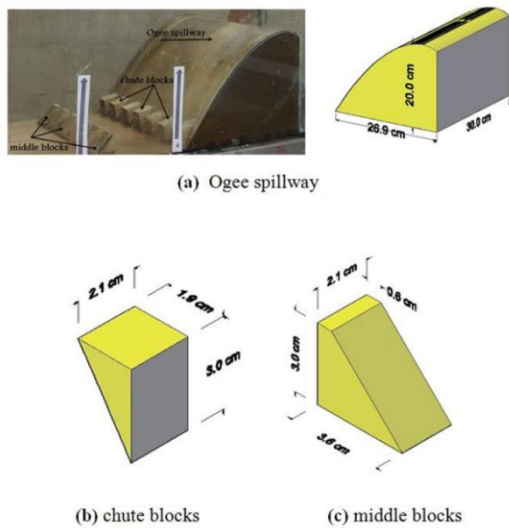


Figure 4. Details of all elements of laboratory models

2.4 Test Procedure

In this section, the tests practice on the two cases depending on the design and laboratory model data. In each test, three sensor reads of water level gathered. Two sensor reads in upstream at a distance (10 cm and 60 cm) from spillway beginning; while the third sensor read in downstream at a distance (120 cm) from spillway toe as illustrate in Fig. 5.

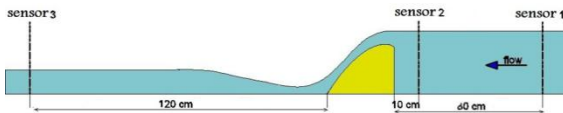


Figure 5. Schematic representation of the sensors measurement sections

The same laboratory test procedure was followed in the two cases. This test is summarized as follows:

- Operating the flume pump.
- Adjusting the flowmeter to obtain the required flow rate.
- Measuring the upstream water depth.
- Measuring the downstream water depth.
- Measuring the longitudinal hydraulic jump toe position.

2.5 Energy Dissipation Calculations

In general, energy dissipation is described by the difference between the upstream and downstream total energy. So, energy dissipation at dams and weirs is closely associated with spillway design, particularly with the difference between the upstream and downstream water levels.

In hydraulics, for channels of small slope, the total energy at the channel section is measured by Bernoulli Equation below [9]:

$$E = z + d + \alpha \frac{V^2}{2g} \quad \dots 2$$

where, E is the total energy of flow in m, z is the elevation of a datum in m that is represented by flume zero slope bed, d is the depth below the water surface in m measured along the channel section, V is the flow velocity in m/s, g is the gravitational acceleration in m/s<sup>2</sup> and α is Coriolis coefficient. In ogee weir, the Coriolis coefficient is equal to one [8]. The relative energy dissipation is the ratio of the energy loss to the upstream total energy [10]. Then the following formula was used to calculate the energy relative loss along the spillway system:

$$\Delta E_r = \frac{\Delta E}{E_u} = \left( \frac{E_u - E_d}{E_u} \right) \quad \dots 3$$

In which the left hand side of the equation represents the relative energy dissipation ΔE<sub>r</sub>(τ). E<sub>u</sub> is the total flow energy at the upstream of the spillway in m. E<sub>d</sub> is the total flow energy at the downstream of the spillway in m. ΔE is the difference in the energy between upstream and downstream of spillway in m.

3. Results

3.1 Verification of design model and laboratory model

By fixing the same design values of ( h<sub>e</sub> ) for the 11 runs were measured by the sensor 1, A model discharges were obtained from these runs as shown in Table 1.

Table 1. The design and laboratory models discharges ( Q<sub>d</sub> & Q<sub>l</sub> ) with respect to ( h<sub>e</sub> ) values

h <sub>e</sub> (m)	0.062	0.066	0.070	0.074	0.077	0.081	0.085	0.088	0.091	0.095	0.098
Q <sub>d</sub> (m <sup>3</sup> /s) calculated by eq.1	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020
Q <sub>l</sub> (m <sup>3</sup> /s) measured	0.0095	0.0105	0.0116	0.0125	0.0137	0.0149	0.0159	0.0170	0.0181	0.0193	0.0203

Q<sub>d</sub> and Q<sub>l</sub> were inserted into Curve Expert 2.2.3 software program in order to get the linear regression. The quality of this fit in design discharges and laboratory discharges was quantified by R<sup>2</sup> = 0.97 as shown in Fig. 6. A scatter of points relative to the linear regression indicated that the design and laboratory values were in good agreement.

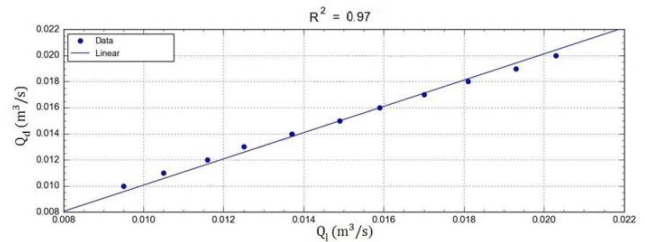


Figure 6. Verification between Q<sub>d</sub> and Q<sub>l</sub>

3.2 Relative energy dissipation results

To investigate the effect of using blocks in the ogee-spillway toe and stilling basin on relative energy dissipation, experiments were performed at various discharges for the two cases. Table 2 shows the relative values of energy dissipation of these two cases.

Table 2 Relative energy –dissipation ΔE<sub>r</sub> for the two cases

Q (m <sup>3</sup> /s)	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020
ΔE <sub>r</sub> Case1	0.628	0.593	0.578	0.550	0.523	0.511	0.508	0.499	0.482	0.474	0.452
ΔE <sub>r</sub> Case2	0.703	0.692	0.682	0.672	0.666	0.660	0.648	0.574	0.535	0.506	0.456

Fig. 7 shows the effect of using blocks in spillway and stilling basin. When studying case1, the rate of energy dissipation decreases by increasing the discharge from 0.01 m<sup>3</sup>/s to 0.020 m<sup>3</sup>/s, with a difference in the dissipation energy of (17.6%). The rate of energy dissipation for case2 decreases at a small rate by increasing the discharge from 0.01 m<sup>3</sup>/s to 0.016 m<sup>3</sup>/s with a difference in dissipation energy of (5.5%), while the rate of energy dissipation decreases significantly with increasing discharge after 0.016 m<sup>3</sup>/s to 0.020 m<sup>3</sup>/s with a difference in dissipation energy of (19.2%), then the accumulation of difference in the dissipation energy is (24.7%).

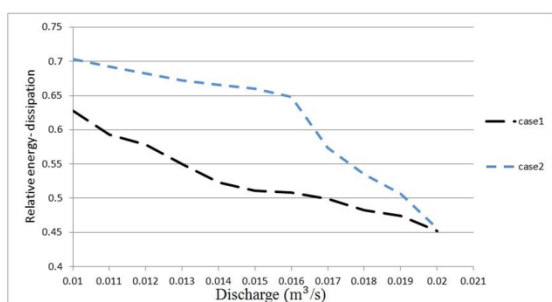


Figure 7. Difference in relative energy dissipation versus discharges for the two cases

### 3.3 The longitudinal hydraulic jump toe position results

The proportions of a stilling basin are frequently designed according to the features of the hydraulic jump that form inside the basin. An investigation was carried out to find out how blocks elements effects on the longitudinal hydraulic jump toe position. Fig. 8 shows the experimental hydraulic jump toe position (d) which is measured by graded ruler fixed on sidewall of the flume. Table 3 presents the comparison in (d) values between the two cases. Fig. 9 represents the difference in (d) values versus discharges for the two cases.

Table 3. longitudinal hydraulic jump toe position(d) in stilling basin for the two cases

Q (m <sup>3</sup> /s)	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020
d (m) Case1	3.80	4.40	4.60	5.00	5.60	5.80	6.20	6.80	Nil	Nil	Nil
Case2	0.61	0.62	0.63	0.64	0.65	0.72	1.20	1.50	1.80	2.00	2.15

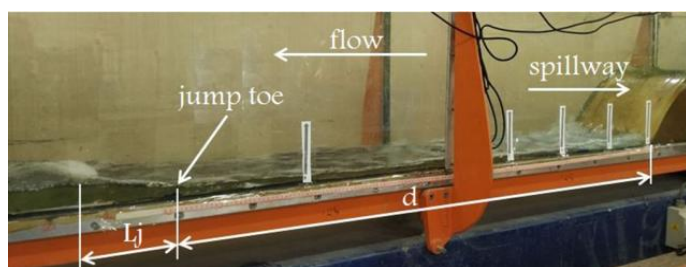


Figure 8. The experimental hydraulic jump toe position (d)

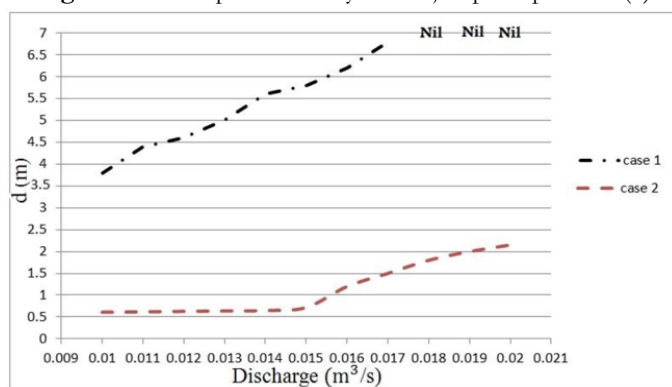


Figure 9. Difference in the longitudinal hydraulic jump toe position (d) versus discharges for the two cases

## 4. Results and discussions

This research focused on using blocks in stilling basin and spillway. This research contributes to basic knowledge regarding these dissipating structures. To this aim, two different cases were experimentally investigated. In fact, as the using of blocks in stilling basin, the flow direction changed to be more upward, causing more dispersion in the air and consequently more energy dissipation. By

increasing the discharge in two cases, relative energy dissipation was also decreased because flow resistance was reduced. Blocks are used when energy has to be dissipated for large-velocity flows. However, it is still an issue to investigate the cavitation between blocks in the stilling basins, and the effect of a blocks on erosion downstream spillway, caused by jet flow and a variety of shapes of blocks with the position and arrangement of blocks on the stilling basin base. In this research, the effect of a using blocks in stilling basin on the amount of kinetic-energy dissipation was experimentally investigated. The design model was first compared with laboratory model to demonstrate the suitability of calculations for adequately flow features. Subsequently, changes to numerous independent parameters were made using a laboratory test to determine their effect on the amount of kinetic-energy dissipation. Changes included modifications to blocks, and discharge. Moreover, the average amount of energy dissipation in stilling basin with blocks is (61.8%) compared to that in a smooth stilling basin which is (52.7%) increased by (9.1%) for discharges of water range from (0.010 m<sup>3</sup>/s to 0.020 m<sup>3</sup>/s). The use of blocks in the stilling basins gives a higher dissipation energy than the use of smooth stilling basins due to place these blocks in the path of the flow, as volume occupied by appurtenances helps to create a backwater problem [11].The possibility of using case2 to give stable and better energy dissipation results until rate of discharge (0.016 m<sup>3</sup>/s), then the energy dissipation decrease in a high ratio till discharge (0.020 m<sup>3</sup>/s). In general, case2 can be considered more suitable for use than case1. Also, the using of blocks in stilling basin and spillway led to decrease the longitudinal hydraulic jump toe position (d) because of the jump is very sensitive to tail water depth at these low values of the Froude number, a slight deficiency in tail water depth may allow the jump to sweep completely out of the basin [11].This is found in table 3 and by comparing (d) values in this table for the two cases, there are a decrease in (d) values in case2 compared to case1, and that the percentage of decrease in (d) values were (83.94%, 85.90%, 86.30%, 87.20%, 88.39%, 87.58%, 80.64%, 77.94%) for the discharges tests from ( 0.010 m<sup>3</sup>/s to 0.017 m<sup>3</sup>/s ). In case1, it is not possible to observe and measure (d) values for discharges tests from ( 0.018 m<sup>3</sup>/s to 0.020 m<sup>3</sup>/s ) due to the insufficient length of the flume used in the laboratory.

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