International Journal of GEOMATE, June, 2020, Vol.18, Issue 70, pp. 215 - 220
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.70.9278
Geotechnique, Construction Materials and Environment

MODELING OF USBR TYPE II ENERGY REDUCER TO IMPROVE ENERGY REDUCTION IN STILLING BASINS WITH HYDRAULIC PHYSICAL MODEL TEST

Syaiful Anam[1], Very Dermawan[2] and *Abu Bakar Sambah[3]

[1]Department of Civil Engineering, University of Brawijaya, Indonesia.
[2]Faculty of Engineering, University of Brawijaya, Indonesia
[3]Faculty of Fisheries and Marine Science, University of Brawijaya, Indonesia

*Corresponding Author, Received: 16 June 2019, Revised: 08 Jan. 2020, Accepted: 24 Feb. 2020

ABSTRACT: The main building in an irrigation network building can be defined as a building complex along the river where buildings can divert water to an irrigation channel so that the water can be used for irrigation purposes. If a weir is built, a water jump will occur downstream of the weir. The speed in the area is still high so that a construction of energy absorbers is made. Energy reducer is a hydraulic building which built to reduce energy of water that caused from the runoff of the top of the dam lighthouse. The construction of energy absorbers has several types including the type of Vlughter, Schoklitsch, Bucket, USBR, and The SAF Stilling Basin. In this study, the type of USBR II energy reducer is used, which is an energy reducer which has sharp channel blocks (dispersing teeth) at the upstream end and near the end of the downstream (end sill) and this type is suitable for flow with hydrostatic pressure greater than 60 m. The purpose of this study is to efficiently the model of energy absorbers by modifying the reduction the elevation in the energy absorbing floor type USBR II. This research was conducted at the Laboratory of River and Swamp, Water Resources Engineering, Faculty of Engineering, University of Brawijaya Indonesia by testing the physical model in accordance with the design work of South Borneo Kambat Dam, with a physical model of open channels with a width of 40 cm, fixed base, scalatic and using clean water.

Keywords: Energy, Basin, Hydraulic,USBR

1. INTRODUCTION

Main building (headworks) in an irrigation network can be defined as a building complex on or along a river where the building as a whole can divert water to an irrigation channel so that the water can be used for irrigation purposes. The main building consists of a complex of buildings, among others: (i) Building a dodger that is part of the main building that functions to divert the direction of the flow of the river into the channel (for example: weir) with energy absorbers; (ii) Energy dampening, which is part of the evacuation building which functions to reduce the flow of water when passing dam (for example: olak pond); (iii) Mud bag, which is part of the main building that functions to deposit or contain sediment from the river so that it does not enter into the irrigation canal until during rinsing; (iv) Rinsing building, which is part of the main building that functions to rinse the sediment.

If a weir construction is built on the river flow both on the trough and on the line, then on the downstream of the weir there will be a water jump. The speed in the area is still high, this will cause local scouring. To reduce the high speed, an energy damper construction is made. The hydraulic form is a form of meeting between a sloping cross section, a curved cross section, and a straight cross section. In general, the construction of energy absorbers is divided into five types, namely: (1) Vlughter type ponds; (2) Schoklitsch type ponds; (3) Bucket type pool; (4) USBR type pool; (5) Natural swimming type The SAF Stilling Basin (SAF = Saint Anthony Falls).

The Vlughter type olak pool was specifically developed for the plunge building in the irrigation channel. The limits given for z / hc 0.5; 2.0 and 15.0 are associated with the Froude 1.0 number; 2.8 and 12.8. The Froude numbers are taken at z depth below the upstream energy level, not on the pool floor as for the water jumping pool. The Vlughter pool can be used up to z height difference of not more than 4.50 m and or in the olak to mercury room floor (D) no more than 8 meters and consideration of soil porosity conditions at the weir location in the context of drying.

The use of the type of USBR energy absorbers in Indonesia began in 1970 [1]. This type is usually used for head drop that is higher than 10 meters. This processed space has various variations and most importantly there are four types that are distinguished by the hydraulic regime of flow and construction. These types, namely the processing space type USBR I, USBR II, USBR III, and USBR IV.

The use of energy absorbers for weirs based on graphs and published formulas will be over design, this is due to; (1) Sometimes there is no back jump on the floor and sometimes the flow that occurs is higher than the tail water; (2) There is a difference in the determination of the Froude number in full jump (Fr1) and reverse jump (Fr2) conditions where Fr2 <Fr1; (3) Types of energy absorbers can be used for weirs provided that the size needs to be adjusted to the results of the Physical Model Test.

Experiments to determine the hydraulic spring length are not easy due to the occurrence of strong turbulence and the presence of one-phase and two-phase currents which add to the difficulty in measuring flow depth, pressure distribution and hydraulic jump length. According to the Elevatorski (1959), the initial formulation for the hydraulic jump length was carried out by [2]. Then in 1927-1929, Safranez carried out a systematic study of the length of the roll (roller) on hydraulic leaps. Furthermore [3-4] define that the end of the hydraulic jump is a position where the free surface reaches the maximum height. Peterka (1984) [5] examines that the hydraulic spring end is assumed to be the position where the highest beam velocity starts to detach from the base and then glides downstream. The results of Peterka's research are one that is often used to calculate the length of the hydraulic jump in the olak pool.

This research tried to find out the correlation between reduction efficiency, high fall and discharge in channels without negative slope and with negative slope in flat Stilling basins and USBR type II, and to find out the most optimum reduction efficiency and length of jumps that occur in channels without negative slope and with negative slope in flat Stilling basins and USBR type II.

2. METHOD

2.1 Research Variable

The research was conducted at the Laboratory of River and Swamp, Water Resources Engineering, Faculty of Engineering, University of Brawijaya Malang, Indonesia. The implementation of this hydraulic physical model test research uses laboratory facilities, including; (a) physical overflow model with open channel, spillway uses upright Ogee type as fixed parameter with slope of launcher channel is 1:4, fixed channel width is 40 cm; (b) three pieces of water pump to supply clean water flow to the model; (c) water reservoir to supply water to the model and equipped with a discharge measuring device; (d) rechbox discharge measurement tool; (e) point gauge, pitot tube, water pass, measuring rod, measuring cup, bucket, telemetry, and stopwatch.

In this study several variables were used to support the results of this study. The dependent variable consist of; (a) critical depth (Yc); (b) y_1, y_2, y_3; (c) Froude number (Fr); (d) Jump Length (Lj); (e) Jump height (YJ). Moreover, the independent variable consist of ; (a) discharge (Q); (b) ogee spill upright; (c) slope of the launch channel; (d) high damping; and (e) USBR olak pool type II.

2.2 Energy Dissipation

Specific energy is energy relative to the channel base. The amount of this energy as illustrated in Fig. 1 and Eq. (1).

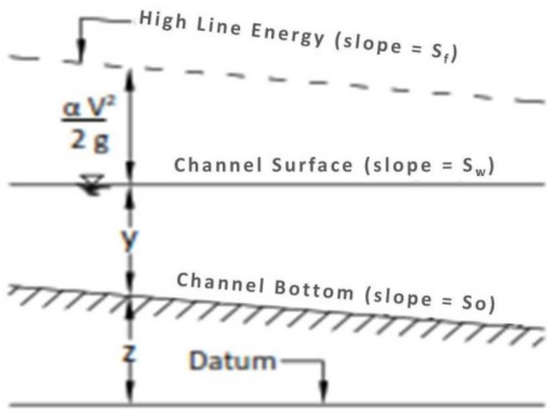

Fig. 1 Energy flow in open channel [6]-[7]

$$E = \frac{av^2}{2g} + y \quad (1)$$

The velocity distribution coefficient (a) can be seen in Table 1.

Table 1. Velocity Distribution Coefficient (a) [8]

Channel	Minimum	Average	Maximum
Ordinary canals, overflow gutters	1.10	1.15	1.20
Natural rivers and heavy rivers	1.15	1.30	1.50
The river is covered by ice	1.20	1.50	2.00
River valleys are flooded	1.50	1.75	2.00

Froude Number (Fr) is defined as the average velocity v divided by the root of gravity g and the depth of water written as Eq. (2) [9].

$$Fr = \frac{v}{\sqrt{\frac{gy}{\alpha}}} \quad (2)$$

Flow in open channels based on Froude numbers can be classified into three parts, namely sub-critical, critical and super critical flow, with the criteria of; (a) sub-critical flow: when Fr<1; (b) critical flow: when Fr=1; (c) super critical flow: when Fr>1.

Hydraulic jumps are the fast transition from supercritical to subcritical flow. This is an extreme turbulence process, which is characterized by large-scale turbulence, surface waves and pounding, energy reduction and air entrainment. The nature of the flow in the downstream and the energy lost in the hydraulic jump can be inferred from the momentum principle as a function of the Froude number upstream and the depth of the upstream flow.

For rectangular channels with horizontal flat shapes, the downstream flow depth is described as Eq. (3).

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8{F_r}^2} - 1\right) \qquad (3)$$

The depth before hydraulic jump (y_1) and the depth after hydraulic jump (y_2) are also called the conjugation depth. Hydraulic jumps can be distinguished based on Froude numbers like the following Table 2.

Table 2. Classification of Hydraulic Jumps on Horizontal Square Channels [10]

Fr	Definition	Information
1	Critical flow	No jumps are formed
1.0 - 1.70	Choppy jumps	There are waves on the surface of the water
1.70 - 2.50	Weak jumps	Small energy loss
2.50 - 4.50	Oscillating leaps	Irregular oscillating bursts produce large waves towards the downstream, damaging and eroding the dikes.
4.50 - 9.00	Steady jumps	Energy reduction is 45–70%. Hydraulic jumps are very balanced. Not too affected by downstream conditions. The best economic planning
> 9.00	Strong jump	Strong jump. Energy reduction up to 85%. The risk of erosion at the bottom of the channel to watch out for.

2.3 Energy Loss

The loss of energy in jumping is the same as the specific energy difference before and after the jump. The amount of energy loss as defined in Eq. (4).

$$\Delta E = E_{1-}E_1 = \frac{(y_2 - y_1)^2}{4y_1y_2} \qquad (4)$$

An equation for energy loss in uniform flow and non-uniform flow in smooth launch channels as shown in Eq (5) [9].

$$\Delta E = y_w \cos\theta + \alpha \frac{{q_w}^2}{2g{y_w}^2} \qquad (5)$$

Previous research was developed kinetic energy coefficients for sinking flows on launchers with values of 1.1 - 1.6 [10-11-12]. The research step is described in the flow chart in Fig. 2.

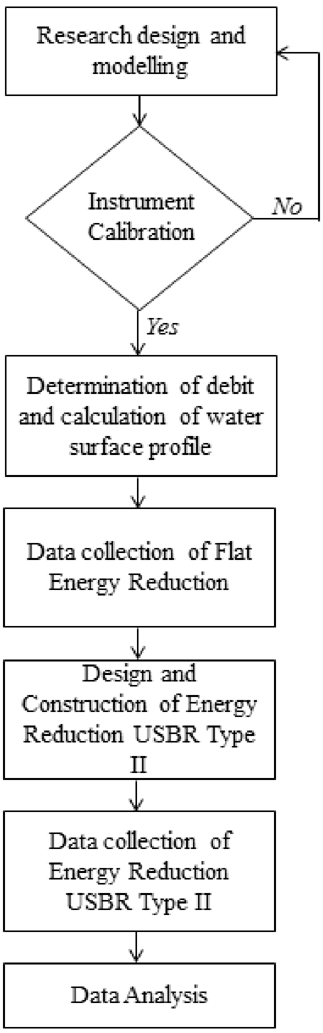

Fig. 2 Research flow chart

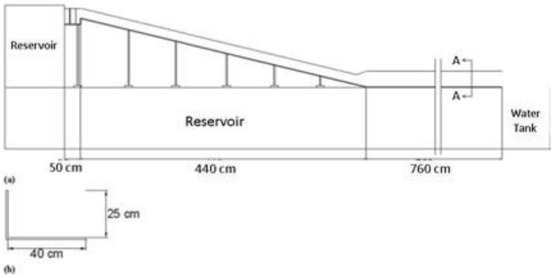

Fig. 3 (a) Research Channel Model in the Laboratory; (b) A-A Pieces of the Research Channel Model

3. RESULT AND DISCUSSION

3.1 New Discharge Calculation between Thompson Discharge and Measure Discharge

The calculation of the new discharge is done by finding a relative error and correction discharge between the Thompson discharge and the measuring discharge. Then look for a new discharge value through the equation from the graph obtained from the correction discharge.

The steps to find a new discharge value are as follows:

Example of calculation (*h* thompson = 5.1cm);

1. Finding Relative Mistakes (Kr)

$$Kr = \frac{Qmeasure - Qthompson}{Qmeasure} = \frac{0.850 - 0.842}{0.850} = 0.010$$

2. Finding the Correction Discharge Coefficient (K)

$$K = \frac{Qmeasure}{Qthompson} = \frac{0.850}{0.842} = 1.010$$

From the calculation of the correction discharge coefficient it shown the smallest correction discharge coefficient value is 0.978 at h thompson 6.75 cm.

3. Finding Corrected Discharge

$Q_{correction} = Q_{measure} \times K$

= 0.850 x 0.978 = 0.831 l/s

4. Finding the relative error of Correction Discharge

$$Kr = \frac{Qmeasure - Qcorrection}{Qmeasure} = \frac{0.850 - 0.831}{0.850} = 0.022 \text{ l/s}$$

5. Finding New Discharge

The calculation is obtained from the graph of the relationship between h Thompson and correction discharge (Fig. 4).

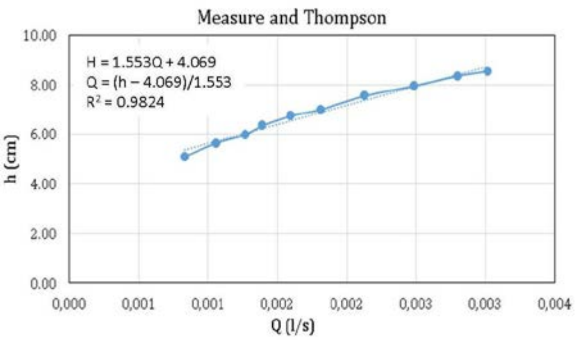

Fig. 4 Graph of the relationship between Q and h

From the graph above, statistics are used to calculate Thompson's new discharge. Calculation as follows;

Example of calculation (h thompson = 5.1 cm)

$\boldsymbol{h = 1.553Q + 4.069}$

from above algoritm, $\boldsymbol{a = 1.553}$ and $\boldsymbol{b = 4.069}$, so:

$$\boldsymbol{h = aQ + b}$$

$$\boldsymbol{Q = \frac{h - b}{a} = \frac{5.1 - 4.069}{1.553} = 0.664\ l/s}$$

Discharge value at h thompson 5.1cm is 0.664 l/s.

3.2 Calculation of Flat Energy Reduction

The measured data is critical depth (*yc*), y_1, y_2, *Lj*. Measurement data as shown in Table 2.

Table 2. Calculation and Measurement Results of Flat Energy Reduction

h Rechbox (cm)	Q (l/s)	Theoretical		
		Yc (cm)	*y_1 (cm)*	*y_2 (cm)*
7.00	11.004	4.257	1.392	9.855
8.00	13.019	4.762	1.544	11.080
9.00	15.102	5.257	1.692	12.287
10.00	17.246	5.744	1.836	13.478
11.00	19.446	6.222	1.981	14.636

Measurement of Flat Energy Reduction				
Yc (cm)	*y_1 (cm)*	*y_2 (cm)*	*Kr y_2 (%)*	*Lj (cm)*
4.300	1.400	10.650	8.071	154
4.750	2.550	11.500	3.787	159
5.250	1.700	12.300	0.103	162
5.750	1.850	13.150	2.431	181
6.300	2.000	14.700	0.435	87

From the data above, it can be seen that the critical depth (*yc*) and y_1 between the theoretical results and the measurement results have relatively the same value, whereas for the value of y_2 it has a relative error of less than 10%.

3.3 Calculation of Energy Reduction Buildings (USBR Type II)

The energy absorbers used in this study are USBR Type II energy absorbers. The calculation of the USBR Type II energy absorbing building uses data from a 9 cm rechbox h discharge. The calculation steps are as follows:

Known data;

Discharge (Q) = 15.102 l/s

Y_1 = 1.692cm

Y_2 = 12.287cm

1. Calculation of Olak Pool Length (*L*)
   $L = 4.16 \times y_2 = 4.16 \times 12.287$ = 51,115cm
2. Chute Block Design
   a. Chute Block high (h_1)
      $h_1 = y_1$ = 1.692cm
   b. Chute Block width (W_1)
      $W_1 = y_1$ = 1.692cm
   c. Distance between Chute Block (S_1)
      $S_1 - y_1$ = 1692cm
   d. Chute Block distance with the wall
      $0.5 \times y_1 = 0.846cm$
3. Block Edge Design
   a. Block Edge high (h_2)
      $h_2 = 0.2 \times y_2 = 0.2 \times 12.287$ = 2.457cm
   b. Block Edge width (W_2)
      $W_2 = 0.15 \times y_2 = 0.15 \times 12.287$ = 1.843cm
   c. Distance between Block Edge (S_2)
      $S_2 = 0.15 \times y_2 = 0.15 \times 12.287$ = 1.843cm
   d. Upper End Block Thickness
      $0.02 \times y_2 = 0.02 \times 12.287$ = 0.246cm

3.4 Result of Launcher Slope 1:4 Measurement without Decreasing Energy Reduction Using Type USBR II

The measurements are made by measuring water level and the velocity. Table 3 and Table 4 are the results of measurements carried out on 5 variations of discharge.

Table 3 Data of Water Level and Jump Length on h Rechbox 7 cm

Water Level and Length					
Q = 11.004 l/s		Calculation (cm)	Measurement (cm)	Froude	Kr (%)
Yc	=	4.257	4.300	1	1.01
Yb	=	3.044	3.050		0.21
Lc min	=	12.771	11.000		13.87
Lc max	=	17.028			35.40
Y_1	=	1.392	2.2		58.04
Yj	=		10.9		
Y_3	=		13.4		
Y_2	=	9.855	11.9	0.2	20.76
Ysill	=		11.6	0.2	
Lyj	=		25.5		
Lj	=		54		

Table 4 Data of theVelocity on h Rechbox 7 cm

Velocity		
Cp	=	0.98 Measurement (cm/s)
Vtransition	=	9.706
Vc	=	63.154
V_{10}	=	148.797
V_{12}	=	174.086
V_{14}	=	181.072
Vy_1	=	225.975
Vj_1	=	9.706
Vj_2	=	9.706
Vy_2	=	16.812
Vsill	=	19.413

4. CONCLUSIONS

It can be concluded that:

1) Decrease of channel without negative slope and with negative slope on the graph of the relationship between reduction efficiency with high fall, the value of reduction efficiency increases every decrease in the channel base i.e at Q = 11.00 l/sec in Original Design the reduction efficiency value is 89.68, Series I 90.46, Series II 90.70, Series III 91.15, Series IV 91.42 and Series V 91.64. This also applies to the USBR type II and to all debits. So it can be concluded that the greater the bottom of the channel (height falls), the greater the efficiency of reduction.
2) The decrease in channel without negative slope and with the negative slope on the relationship graph between the reduction efficiency and the high fall, the value of the relative damping efficiency decreases with each increase in discharge i.e at Q = 11.00 l/sec the value of the reduction efficiency in the original design is 89.68, Q = 13.02 l/sec 89.44, Q = 15.10 l/sec 88.65, Q = 17.25 l/sec 86.87 and Q = 19.45 l/sec 86.79. This also applies to the USBR type II and to all series. So it can be concluded that the greater the discharge the relatively smaller reduction efficiency.
3) Decrease in channel without negative slope and with negative slope on the graph of the relationship between reduction efficiency with discharge, the value of relative reduction efficiency decreases with each increase in discharge
4) Reduction efficiency on flat type energy absorbers and USBR type II can be concluded that the reduction efficiency on channels without negative slope has a greater value than channels with negative slope.
5) The jump length on the flat type energy absorbers and USBR type II can be concluded that the value of the jump length in the channels without negative slope has a value

greater than the jump length in channels with negative slope

5. ACKNOWLEDGMENTS

Authors are thankful to Laboratory of River and Swamp, Water Resources Engineering, Faculty of Engineering, University of Brawijaya Malang, Indonesia. We also thank to postgraduate program of Faculty of Engineering, University of Brawijaya Malang, Indonesia.

6. REFERENCES

[1] Mawardi Erman, Memed Moch, Desain Bendung Tetap Untuk Irigasi, Bandung: Alfabeta, 2002

[2] Woodward S. M., Beebe J. C., Riegel R. M., Theory of The Hydraulic Jump and Backwater Curves, Dayton, Ohio : State of Ohio, Miami Conservancy District, 1917, Technical reports (Miami Conservancy District (Ohio)), pt. 3.

[3] Bakhmeteff B. A., Hydraulics of Open Channel, 1936, p. 70.

[4] Bakhmeteff B. A., and Matzke, Trans, ASCE 101, 1936, pp. 630-680.

[5] Peterka A. J., Hydroulic Design of Stilling Basins and Energy Dissipators, a Water Resources Technical Publication, Engineering Monograph No. 25, 1984, United State Department of Interior, Beureau of Reclamation.

[6] Chaudhry H., Schleip R., Ji Z., Bukiet B., Maney M., Findley T., Three-Dimensional Mathematical Model for Deformation of Human Fasciae In Manual Therapy, J Am Osteopath Assoc, 108 (8), 2008, pp. 379-90.

[7] Chaudhry H., Open Channel Flow, Springer US, Edition Number 2, 2008, p. 523

[8] Chow, Velocity Distribution in Open Channel Flow, Journal of Hydraulic Engineering 115 (5), 1989.

[9] Chow, V. T., Open Channel Hydroulic, New York: McGraw-Hill, 1959.

[10] Chanson, H., The Hydraulics of Open Channel Flow: An Introduction, Butterworth-Heinemann, Oxford, UK, 2nd edition, 2004, 630 pages.

[11] Boes R. M., and Willi H., Hager Closure to Hydraulic Design of Stepped Spillways, Journal of Hydraulic Engineering, 131 (6), 2005.

[12] Matos J., Sanchez M., Quintela A., and Dolz J., Characteristic Depth and Pressure Profiles In Skimming Flow Over Stepped Spillways, in: *Abstrs. of the XXXVIII IAHR Congr.*, Graz, 1999.