Restricting Hydraulic Jump Location inside stilling Basin for Maximum Energy Dissipation

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Abstract - *As per the report of International Commission on Large Dams (ICOLD) 20% of dam mishaps happened because of poor arrangement of energy dissipation. Normally, energy dissipators are only intended for 'design discharge' of spillway. In this manner there is a need to build up a proper plan to perform expected function of energy dispersal even at lower discharge. Present work is focused on hydraulic jump type energy dissipators. It is found that in majority of failure cases of dam, the jump position is not specified – i.e. jump is either swept up or drowned. So it is required to manage the position of hydraulic jump so that the front of jump is positioned near toe of spillway or sluice gate to get clear jump. When the ideal post jump depth is equal to value obtained by Belanger momentum equation, then only clear hydraulic jump occur. To control and restrain the location of hydraulic jump in basin , a stepped weir is proposed at the end of apron. And mathematical method is performed to design the weir geometry which will form desired post jump depth corresponding to any discharge between design discharge and 20% of the design discharge. Analysis in ansys fluent demonstrate that, for horizontal aprons, a designed weir section restricted the hydraulic jump to its desired location for different discharges.*

Key Words: **Hydraulic jump, Position of jump, Ansys fluent, Stepped weir, Energy dissipation**.

1. INTRODUCTION

Energy dissipators in form of hydraulic jump are generally used for energy dissipation while planning the hydraulic structures like dams, weirs and barrages. They are popular for simplicity and proficiency, yet have certain restrictions when there is changes in discharge conditions. The energy dissipators agreeably work at design discharge condition. But if there is occurrence of fluctuating discharge conditions, they are not productive as the position of hydraulic jump tends to move from apron. This would bring about decrease in energy dispersal and thus harm hydraulic structures and unfavorably influence tail channel conditions. Henceforth with a plan to resolve this issue, an endeavor has been made to make a constrained hydraulic jump at sought area for fluctuating discharge conditions.

The constrained hydraulic jumps are utilized for energy dispersal in stilling basin. It is a jump shaped with the help of baffles and sill with or without sub critical tail water. A hydraulic jump occur when a high rate supercritical stream all of a sudden changes into a moderately low rate subcritical stream, joined by development of vortexes, rollers and turbulence alongside air entrainment. At last the energy is dispersed as heat. The development of hydraulic jump at the toe of spillway or under the foot of sluiceway goes about as an energy dissipator. The most extreme energy dissipation happens when an clear hydraulic jump occur at the segment where the pre jump depth is least. This is on account of when pre jump depth is least, according to Belanger condition, it's sequent depth i.e. post jump depth is most extreme and consequently the proportion of post jump depth to pre jump depth is greatest and thus the underlying Froude number is greatest. As energy dispersal is specifically related to initial Froude number, for the given inflow condition the energy dissipation is greatest. It is already understood that the length of the apron relies on the length and area of the jump , which thus relies upon the pre jump depth (y1) and the relative extents of post jump depth (y2) and tail water depth (yt).In a rectangular channel with horizontal slope, hydraulic jump forms at a location where these sequent depths satisfy Belanger equation. The sequent depths are referred relating to the segment at vena contracta as the perfect location of jump is at vena contracta of supercritical stream. In case of occurrence of spillway flows the vena contracta would be referred to a segment where the prejump depth (y1) is least. In the case of tail water deficiency condition, the tail water rating curve is lower than the jump height curve for every single discharges. Because of this the hydraulic jump may occurs halfway or completely clear out of the basin and this condition is not recommended as it would bring about harm to stilling basin, tail channel and other downstream structures. Subsequently it turns out to be especially noteworthy to have the area of hydraulic jump in a stipulated zone, to effectively fulfill the purpose of energy dissipation. For this reason the depth of water on the apron might be artificially raised to such an extent, such that it becomes sequent to the pre jump depth at vena contracta and form the jump at vena contracta. This can be accomplished by presenting an obstruction as weir toward the finish of the apron. Normally the rectangular wide crested weirs are considered for this purpose. The weir with its height intended for fix discharge condition, is not appropriate under field conditions where discharges would differ by small and large and not as much as configuration discharges. Accordingly to address this issue an effort has been made to design an end weir geometry which would guarantee development of clear jump at vena contracta for the planned discharge and also for the lower discharges.

2. METHODOLOGY

2.1 Important Factors

The variables which represent design of stepped weir geometry are as per the following –

Head on upstream	=	H
Width of channel	=	B
Maximum discharge in the range	=	Q max
Minimum discharge in the range	=	Q min
Coefficient of discharge	=	C_d
Submerged flow coefficient	=	K
Starting height of weir crest	=	y'

2.2 Mathematical procedure

The stepped weir is designed for the range of configuration discharge (Qmax) to least discharge equivalent to 20% of the design discharge (Qmin). A stepped weir is considered to be made up of number of rectangular weirs. The equation for discharge Q over a rectangular sharp crested weir (free flow) is given by following equation.

$$Q = \frac{2}{3} C_d b \sqrt{2g}\,(y_2 - y')^{\frac{3}{2}}$$

Where h = y_2 – y ', the required width of weir can be found from above equation.

$$b = \frac{3}{2} \frac{Q}{C_d \sqrt{2g}\,(y_2 - y')^{\frac{3}{2}}}$$

Where, y′ = $(y_2)_1$ / 4 is designed for Q_1 (i.e. Q_{min}) . $(y_2)_1$ is the post jump depth corresponding to Q_1 and is calculated by Belanger momentum equation in the following manner.

$$(y_2)i = \frac{(y_2)i}{2}\left(-1 + \sqrt{1 + (8(Fr_1)^2)}\right)$$

For $i \geq 1$

Where $(y_2)i = \frac{Q_i}{BV}$,$= \sqrt{2gH}$, $(F_{r_1})i = \frac{V_1}{\sqrt{g y_1}}$

To calculate width for any other discharge Q_n, the width of the corresponding step can be calculated as follows

$$b_n = b_{n-1} + a_n \dots\dots\dots n > 1$$

Where a_n symbolizes the incremental width at n^{th} step at every rise.

$$a_n = \frac{3}{2} \frac{Q_n - \left[\sum_{i=1}^{i=n-1} (Q_n) i\right]}{C_d \sqrt{2g}\left((y_2)n - (y_2)\right)^{\frac{3}{2}}}$$

And $(Q_n)i = \frac{2}{3} C_d b \sqrt{2g}\,\left((y_2)n - y'\right)^{\frac{3}{2}}$

2.3 Determination of Appropriate C_d for Free Flow Condition on Horizontal Apron

In the mathematical design of stepped weir, for free flow condition, a constant value of C_d = 0.623 is adopted according to Francis formula. As there are different kinds of uncertainties involved in the flow conditions, the analytical determination of C_d is hardly possible. There is presence of hydraulic jump and associated turbulence on upstream of stepped weir. The upstream reach for the stepped weir, being equal to length of stilling basin, is small. Hence it is decided to empirically judge the appropriateness of C_d. Three weir models, each for Cd=0.6, 0.65 and 0.623 were designed and checked by their performance in ansys fluent. With C_d = 0.6, jumps were found to be shifted in the downstream direction. With C_d = 0.65, the jumps were found to be drowned. With C_d = 0.623, the hydraulic jumps have formed inside the basin and the fronts of jumps in all the cases were found to be located near the sluice gate. Thus C_d = 0.623 is confirmed empirically for the condition of free flow over the weir. Value of width and rise at every step for C_d = 0.623 is shown in following table.

Table-1 : Output of Mathematical Procedure for Data(Horizontal apron and C_d = 0.623)

Sr. no	Q m^3/s	y1 m	y2 m	H m	Fr1 M	B M
1	0.002 0	0.002 4	0.060 5	0.045 5	18.335 0	0.111 9
2	0.005 0	0.006 2	0.096 5	0.081 4	11.370 9	0.166 0
3	0.006 8	0.008 1	0.109 8	0.094 8	9.9435	0.181 6
4	0.008 4	0.010 0	0.121 6	0.106 6	8.9466	0.194 9
5	0.009 2	0.010 9	0.127 0	0.112 0	8.5487	0.201 0
6	0.010 0	0.011 8	0.132 2	0.117 2	8.1997	0.206 7

The above analysis is performed by Mr. G.A. Hinge, 2012 for varying gate opening in laboratory but in this study, the gate opening at tail is kept 100% open and the results are still found to be satisfactory and reasonable in analysis in ansys fluent software.

3. RESULTS

By analyzing the various discharge condition in flume with the help of ansys fluent software, it was found that in all the cases, hydraulic jump start forming at the toe or sluice gate opening. Which is most desirable location for formation of hydraulic jump for maximum energy dissipation. Following are results obtained through ansys fluent analysis.

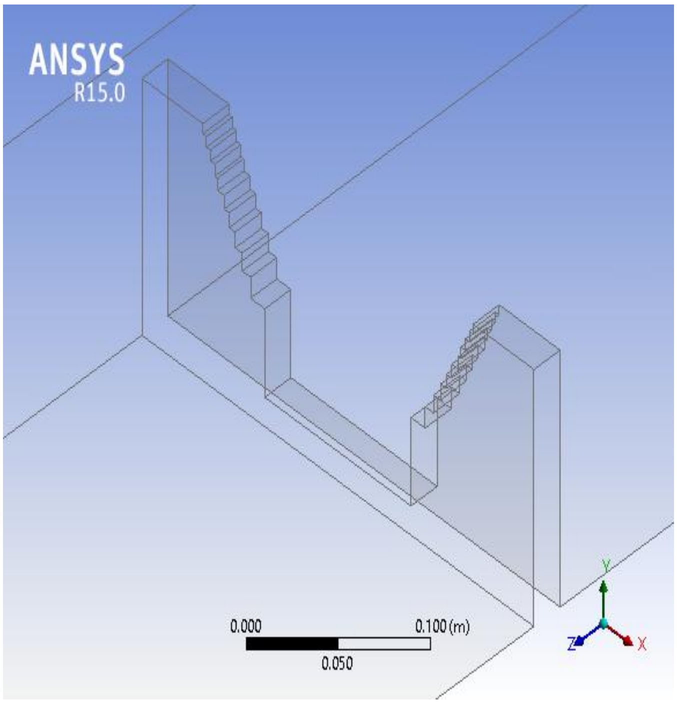

Fig-1: Designed stepped weir for varying Discharge condition

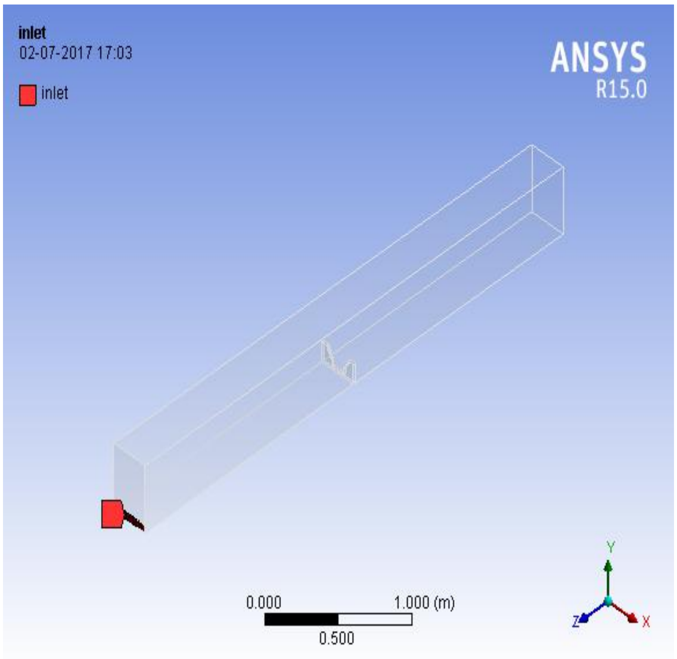

Fig-2: Set up of stepped weir in flume

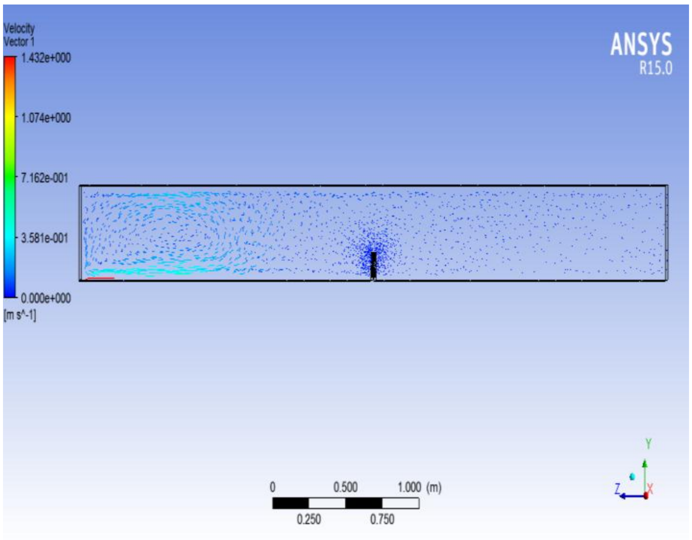

Fig-3: Hydraulic jump formation starting at toe for 20 % discharge

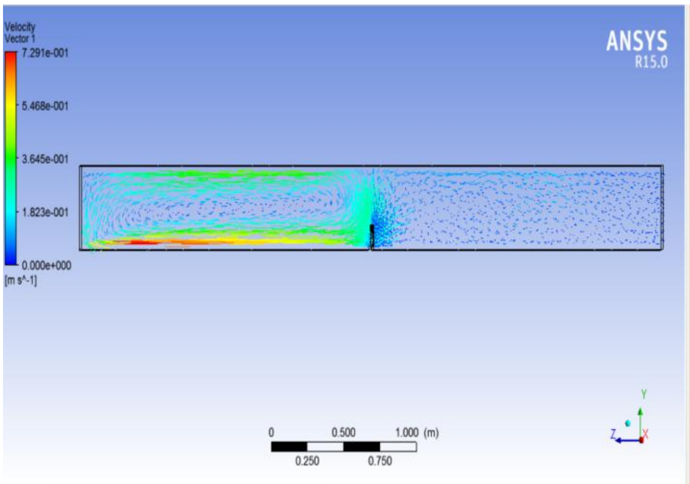

Fig-4: Hydraulic jump formation starting at toe for 50 % discharge

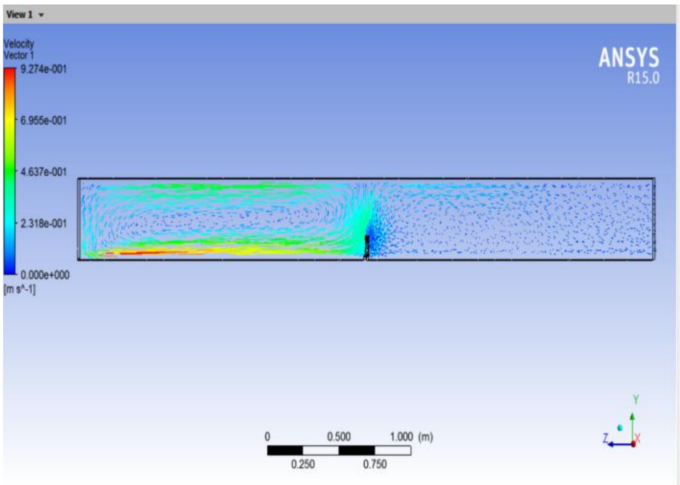

Fig-5: Hydraulic jump formation starting at toe for 68 % discharge

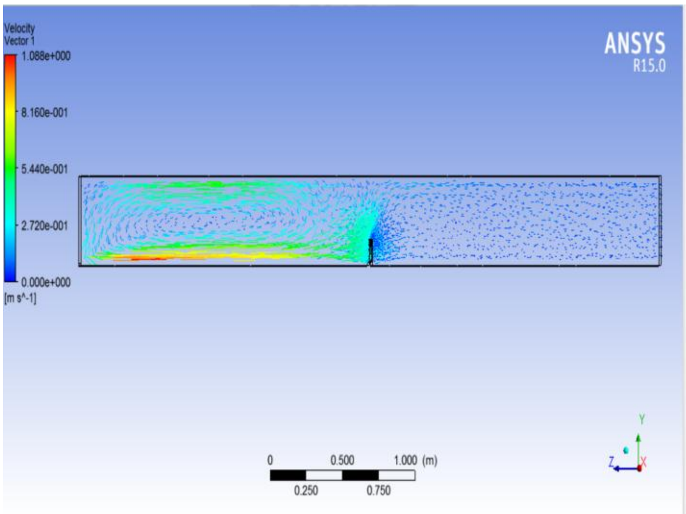

Fig-6: Hydraulic jump formation starting at toe for 84 % discharge

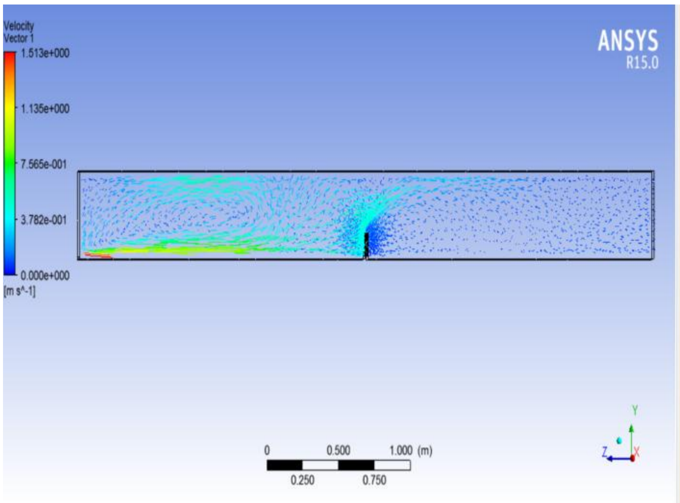

Fig-7: Hydraulic jump formation starting at toe for 92 % discharge

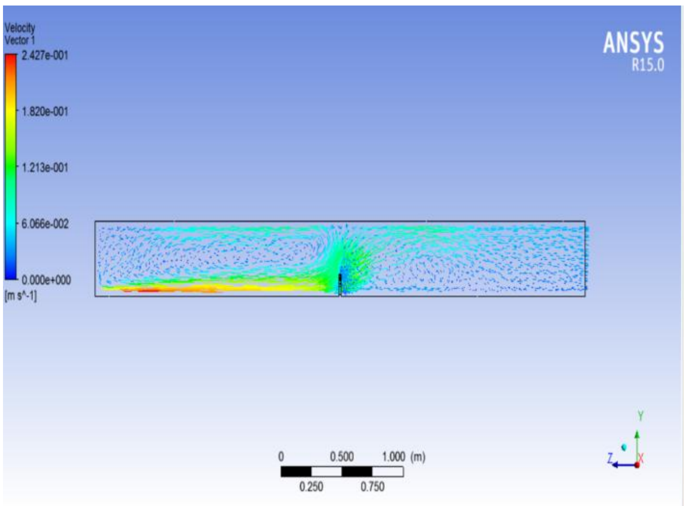

Fig-8: Hydraulic jump formation starting at toe for 100 % discharge

4. CONCLUSIONS AND RECOMMENDATIONS

- The performance of stepped weir is checked for six discharges (20%, 50%, 68%, 84%, 92% and 100% of the design discharge). It is found that for all these discharges clear hydraulic jumps are formed and are located near toe of spillway. Since the location of jump is restricted for most of discharge, it will be beneficial in attaining the purpose of maximum energy dissipation for all discharge.

- The method developed in the study is applicable for steady flow only. Which is F_{r1}> 4.5 .

- Even though this seems to be better method for solving the erosion related problem of stilling basin, but due to too many rectangular sharp edges there are chances of cavitations in weir. Which can be removed on site practice by using least square method for designing cavitation free stepped weir which will be also free from sharp edges.

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