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Investigation of Effect of Changes in Dimension and Hydraulic of Stepped Spillways for Maximization Energy Dissipation

[1]*Saman Abbasi* and [2]*Amir Abbas Kamanbedast*

[1]Islamic Azad University, shoshtar Branch, Iran,
[2]Agriculture Department, Ahwaz Branch, Islamic Azad University, Ahwaz , Iran

Abstract: The stepped spillway has increasingly become effective energy dissipation. The stepped spillway has been accepted to be the most powerful hydraulic structure to dissipate flow energy from ogee spillway. This research presents a numerical model to solve the turbulence Navier- Stokes equations to estimate various parameters, number of steps (N), step height (h), horizontal step length (l), flow discharge per unit width (m^2s) for energy dissipation in of stepped spillways. The relationships between relative energy loss and relative critical flow depth on stepped spillway is presented and discussed. In This research the governing equations solved by finite volume discretization method (flow 3D software) and to estimate the turbulence flow the standard $K - \varepsilon$ model is used. The structured grid is used to fit the irregular boundaries and the volume of fluid (VOF) method is introduced to solve the complex free-surface problem. The free surface, velocities and pressures on the stepped spillway are obtained by the turbulence numerical simulation. Results of the numerical method compare well with the experimental results of other researchers. In addition, the results achieved by numerical solution compared with numerical results shows that in the case of permanent dam's height, the energy dissipation decrease by increase in stairs numbers and water current. Also, in this case, increase in stairs length and heights; cause an increase in energy dissipation.

Key words: Step spillway · Energy dissipation · Flow 3D · K-ε · VOF

INTRODUCTION

Stepped spill way is a kind of structure that has been used for energy dissipating and reducing water erosion at river domain (length) and on steep slope. Practically, this structure is more power full than ogee spill way in order to control flood and energy monitoring at downstream of dams. (when flow has been pouring from spill way; potential energy has been transformed to the kinetic energy). This sort of energy has occurred with very high velocity And it may caused many problem at downstream of river. In order to control and govern these sorts of catastrophic events, it's necessary that some kind of protecting structure such as: steeped spill way has been used to predict energy loss and decreased kinetic energy. Very high percentage of energy has being dissipating, because: stepped spill way may caused the length and height of stilling basin had been decreased definitely and cost of project could been controlled at the correct direction. Beside (clear water) at spill way ending has been observed when flow passing through stepped spill way and when flow Contact to the wall at angled side of spill structure. The impressive air rate through flood has been influenced on shear stress decreasing and may cause loss dissipating at hydraulic structure. That event is because of mixing water molecules and air and the rate of stress has been declined gradually. In the other side of coin, entrance of high air flux rate at flow may cause that depth of water increasing (at the spill way toe) and estimation of energy loss has been different. According to recent researchs, the best way of loss estimation is using water depth (without air hobble). Many paper and journal report that using mixed depth of water could cause overestimation of energy dissipating. At this study, a physical model (according to the Table 1) with 10 steps and 3 different discharges 0.01852 m^3/s 0.02622 m^3/s, 0.03131 and slop equal 45% has been run successfully and passing flow through the model has been run too.

Corresponding Author: Dr. Amir Abbas Kamanbedast, Agriculture Department, Ahwaz Branch, Islamic Azad University, Ahwaz , Iran.

Table 1: Expriment data for stepped spillway

Group	Q (m3/s)	q (m2/s)	yc (m)	h (m)	L (m)	H-dam (m)	N	Slope
	0.01236	0.025	0.040	0.1722	0.1722	1	5	45
	0.01952	0.039	0.054	0.1722	0.1722	1	5	45
	0.0282	0.057	0.069	0.1722	0.1722	1	5	45
	0.01236	0.025	0.040	0.085	0.085	1	10	45
	0.01952	0.039	0.054	0.085	0.085	1	10	45
	0.0282	0.057	0.069	0.085	0.085	1	10	45

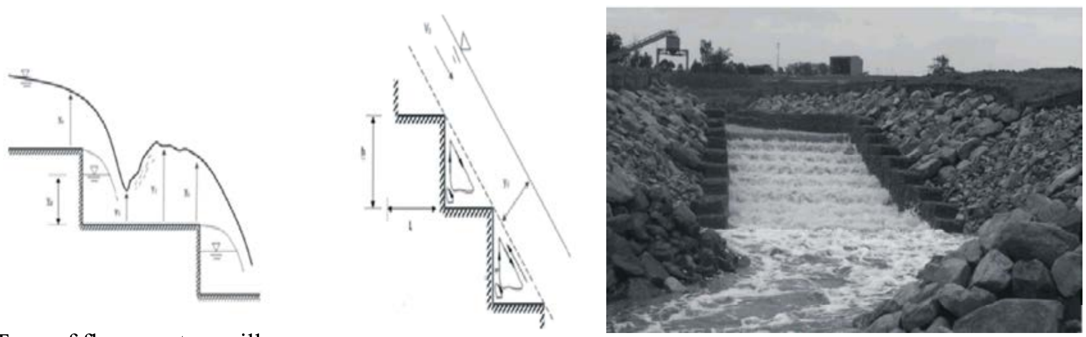

Fig. 1: Type of flow on step spillway

Depth of water before and after jump has been measured accurately with using (accuracy is 0.1 mm) at 3 points and average of data at cross sections for energy loss Calculation. According to the object; for showing error at experiment (initial flood: depth before jump at energy loss calculation), two methods, have been used: One-: directly depth measurement before jump and second depth after jump. Second-: depth determination of conjunctive depth (y1) from hydraulic jump equation [6, 8].

Research Theories

Napped Flow Regime: Flow from upper step with using jet, has been fallen freely. This kind of regime is common for low discharge and high step elevation.

Skimming Flow Regime: At this regime, steps work as high roughness against flow (Figure 1).

Transitional Flow Regime: if flow passed through stepped spill way with variable slope and different numbers of steps and flow is at napped condition, when discharge increased gradually: a new condition has been observed which is transitive between two Flow condition (napped and skimming flow) and this flow regime was known as: transitional flow. (From napped regime transform to the skimming flow condition.

Energy Loss Equation

Energy Loss at Hydraulic Jump Phenomenon: Super critical flow condition at spill way toe or inclined drop structure after hydraulic jump has been transformed to the subcritical condition and through this changing some energy has been lost. Importance of Energy dissipating is because of hydraulic jump (that is related to the stepped spill way with very mild slope and Napped flow regime appearance on spill way). With using energy equation, momentum and continuity formula, energy loss equation has been proved simply.

Energy equation: Hi, j=

$$ES_1 - ES_2 = Y_1 + \frac{v_1^2}{2g} - (Y_2 + \frac{v_2^2}{2g})$$

Energy equation:

$$H_{I,J} = y_1 + hv_1 - (y_2 + hv_2) = \frac{(y_2 - y_1)^2}{4y_1y_2}$$

Momentum equation: for rectangular section:

$$\frac{1}{2}\gamma y_1^2 - \frac{1}{2}\gamma y_2^2 = pq(v_2 - v_1)$$

Continuity equation for discharge per with: $q = v_1y_1 = v_2y_2$

Energy loss equation only at hydraulic jump:

$$h_{i,j} = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

General relation of hydraulic jump:

$$y_2 / y_1 = 1/2(\sqrt{1 + 8fr_1^2} - 1)$$

Energy Loss at Spill Way and Drop Structure: Energy loss at this research means different between upstream energy of spillway or drop structure and downstream (toe) of hydraulic jump location, which has been showed as below:

$$\Delta h = h_1 - h_2 = (1.5yc + h_{dam}) - \left[y_2 + \frac{v_1{}^2}{2g} \right]$$

And none dimensioned energy loss has been defined as bellow:

$$\frac{\Delta H}{Ht} = \frac{H_T - H_1}{H_T} = 1 - \frac{H_1}{H_T = 1} - \frac{\left[Y_1 + \frac{V_1^2}{2g} \right]}{1.5yc + h_{dam}}$$

MATERIALS AND METHOD

Totally, it could be said that, step spillway are: designed with 5, 10 steps and for each group, 3 different discharge per unit. (q=0.025, 0.039 and 0.057) and critical depths equals to 0.04, 0.054 and 0.069 are considered. For modeling flow algorithm, flow 3D software and AutoCAD used simultaneously for meshing, uniform mesh algorithm are utilized. Figure 3 shows meshing around stepped spillway by flow 3D software at each model of 5 stepped groups are 0.085 meter and for 10 stepped groups, height of steppes is 0.1722height of spillway model are similar and equal to 1 meter. Slope of each model are 45° and spillway crest are ogee shape. Table 1 shows each experiment description on stepped spillway.

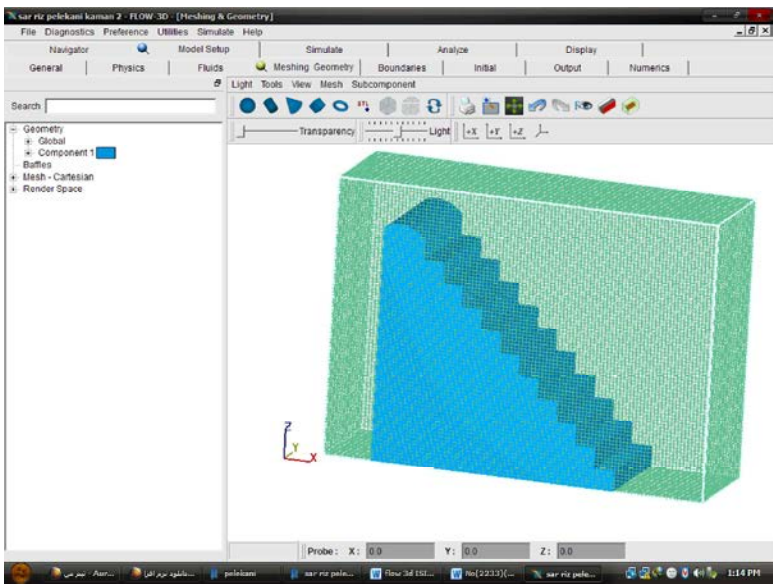

Fig. 2: Sample of meshing for stepped spillway

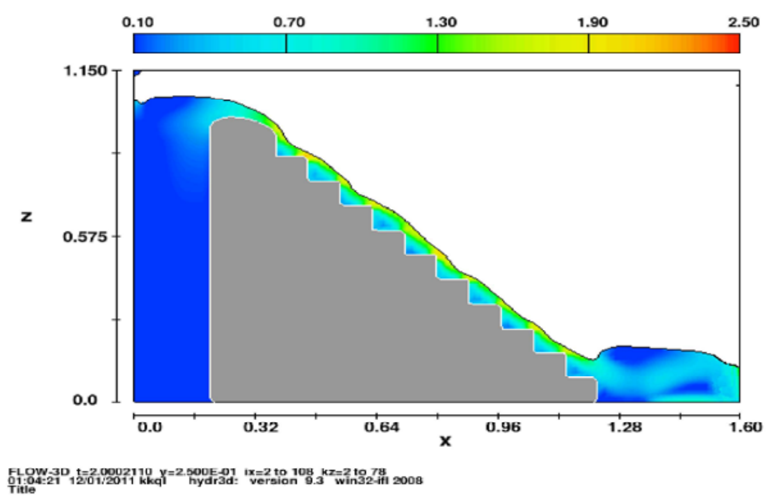

Fig. 3: Water profile frame transitional regime at spillway

RESULT AND DISCUSSION

At Figure 4, 5, 6, 7, flow profile are created for each 3 discharge per unit(q) are equal 0.025, 0.039, 0.057 square meter per second. It can be seen that flow and divided at 3 different regime, nappe, transitional and skimming flow. Water surface profile which are result from dimension all analysis, are skimming flow transitional flow are relatively smooth and coreless increasing flow discharge through stepped spillway are caused flow and the spillway are transitioned to napped flow and dissipating energy are created. Because of discharge increase, flow are transformed from napped to skimming regime and submersible discharge are decrease finally.

Resulted simulation at stepped spillway are shown at Figure 8, 9. Figure 8 show variation of stepped number which indicate that when stepped increase than dissipating efficiency are decreased. When the number sand high are fixed, when length of stepped decline, energy dissipating procedure decreased too. (Because touch surface of steps and flow decreased). Figure 9 shows discharge changing rate at simple stepped spillway. A result, it is conducted that when discharge increase energy dissipating decrease. In fact flow rise caused depth increase and transition from napped to transitional condition and energy dissipating changing rate are appeared.

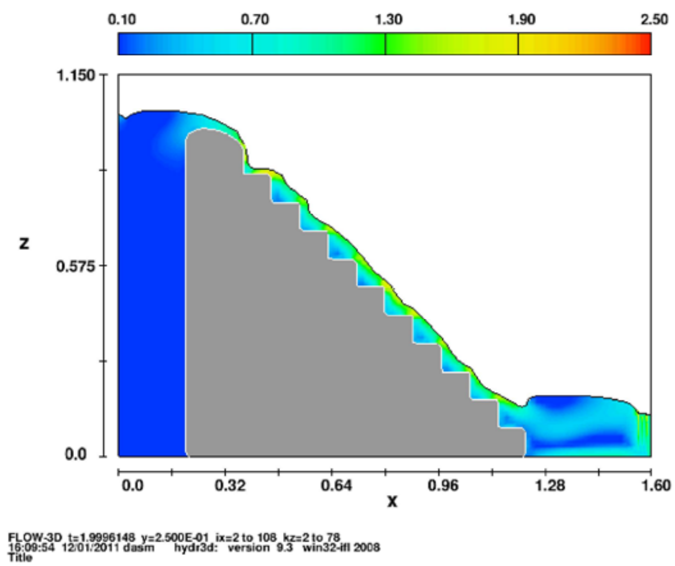

Fig. 4: Profile of skimming flow at stepped spillway

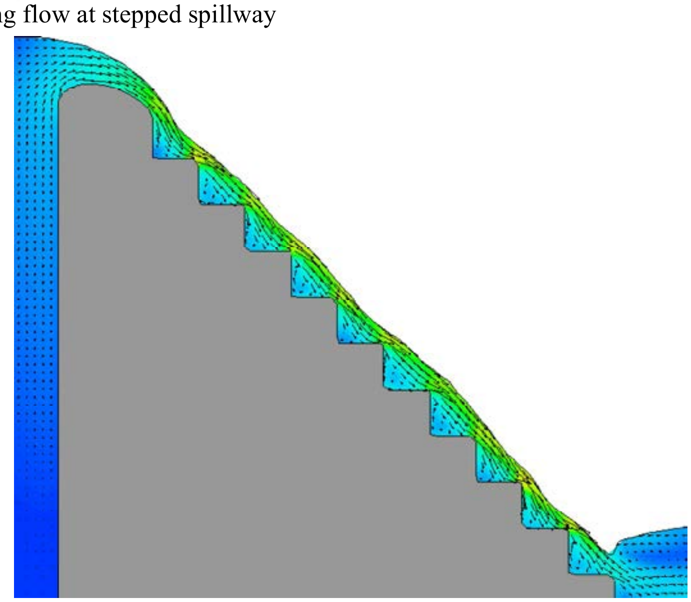

Fig. 5: Meshing of flow algorithm at step spillway

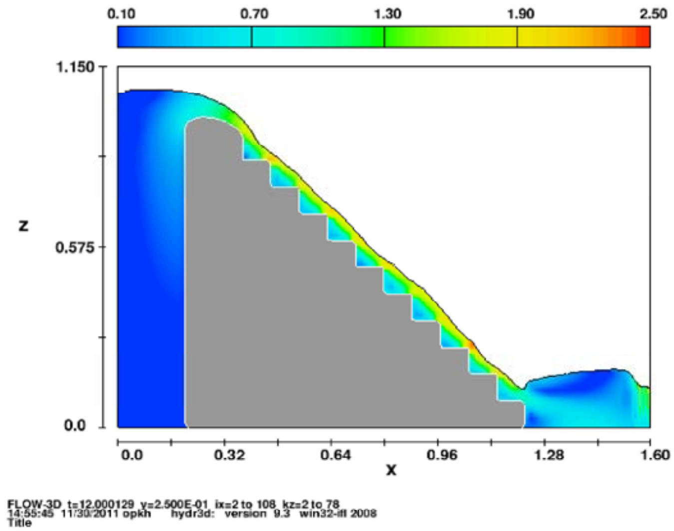

Fig. 6: Flow of continuity at step spillway

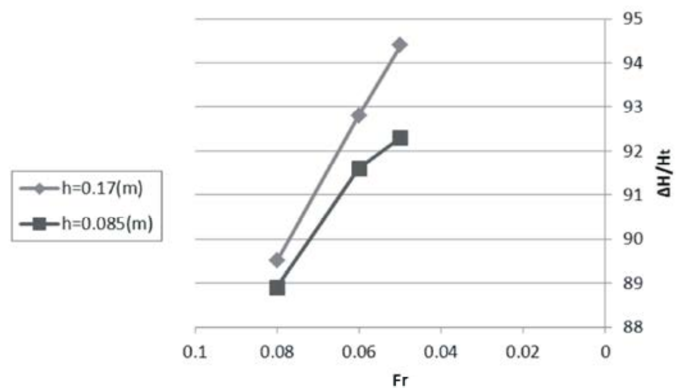

Fig. 7: Graph of energy dissipating against Froude number at different step spillway

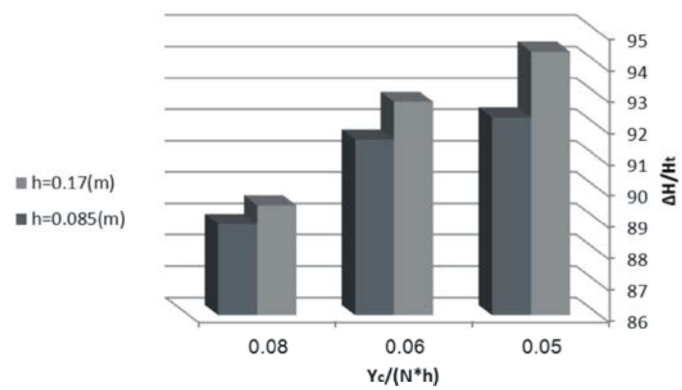

Fig. 8: Graph of energy dissipating against number of steps

Figure 10, 11 demonstrate flow algorithm on 10 stepped spillway and vortex flow.

Comparison of numerical: method and laboratory formal: Table 2, 3 show results of numerical study to empirical formula of Salmasi [8], Chamani and Rajartham [4, 5], Chanson, [2, 3] for sample step spillway. In these two tables which are related to dimensional analysis, it has been observed that numerical method has very good convergence with author's results. At Tables 2, 3 TR is transitional SK is symbol of continuity flow and NA is symbol of napped flow.

Table 2: Comparision of numerical and laboratory simulation (step spillway -group 2)

YC	Numerical method	Salmasi 2003	Boes-Heger 2003	Chanson 1994	Chanson 2001	Chamani and Rajartham 1999
0.04	NA	NA	NA	NA	NA	NA
0.054	NA	NA	NA	NA	NA	NA
0.069	T-NA	NA	NA	NA	NA	T

Table 3: Comparision of numerical and laboratory simulation (step spillway -group 2)

YC	Numerical method	Salmasi 2003	Boes-Heger 2003	Chanson 1994	Chanson 2001	Chamani and Rajartham 1999
0.04	T-S	NA	NA	NA	T-S	T
0.054	T-S	NA	SK	T-S	T-S	SK
0.069	T-S	NA	SK	T-S	T-S	SK

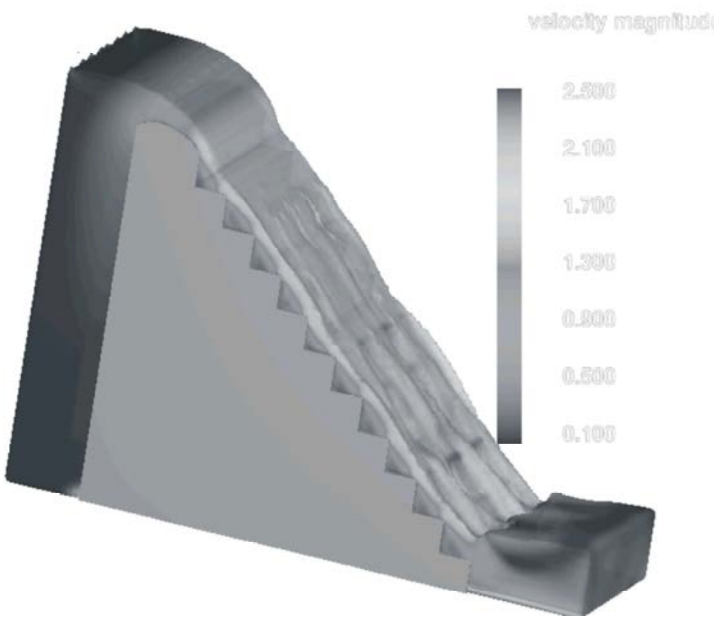

Fig. 9: 3dimensional view of napped flow at 10 stepped spillway

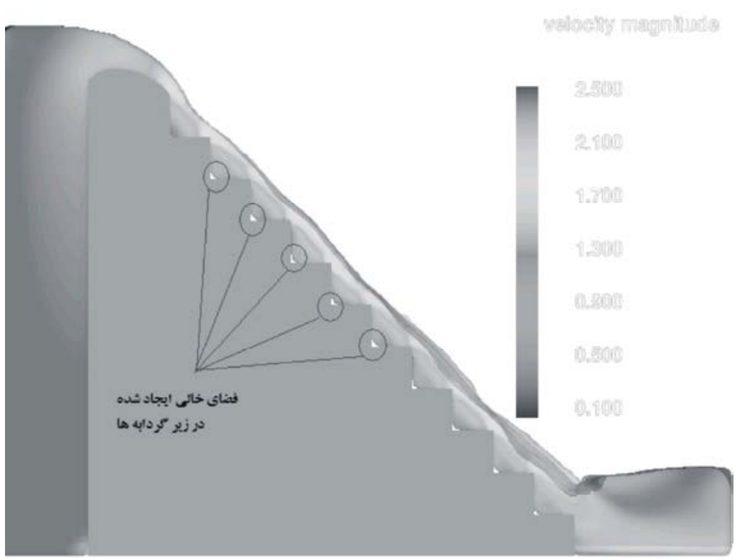

Fig. 10: 3dimentional view of continuity flow at stepped spillway at subcritical situation

CONCLUSION

- According to the results of numerical method in compare with laboratory, it will be concluding that numerical model is very powerful and useful weapon for simulation hydraulic behavior.
- When flow increasable, depth of water rises directly and flow is changed from nappe flow to skimming flow.
- When flow increase then napped flow is created and energy dissipating directly goes done.
- By rising number of steps when height of dam are fixed for stepped spillway, when area stepped faced to flow they are submersible soon and then energy dissipating decreased finally.
- With discharge increasing and difference between energy loss (with consideration depth before and after jump) has been increased logically. This is because of increasing recharge that have influenced on air entrance flux and depth of water is over estimated (after jump) then. Energy loss estimation with using measured depth is more accurate.

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