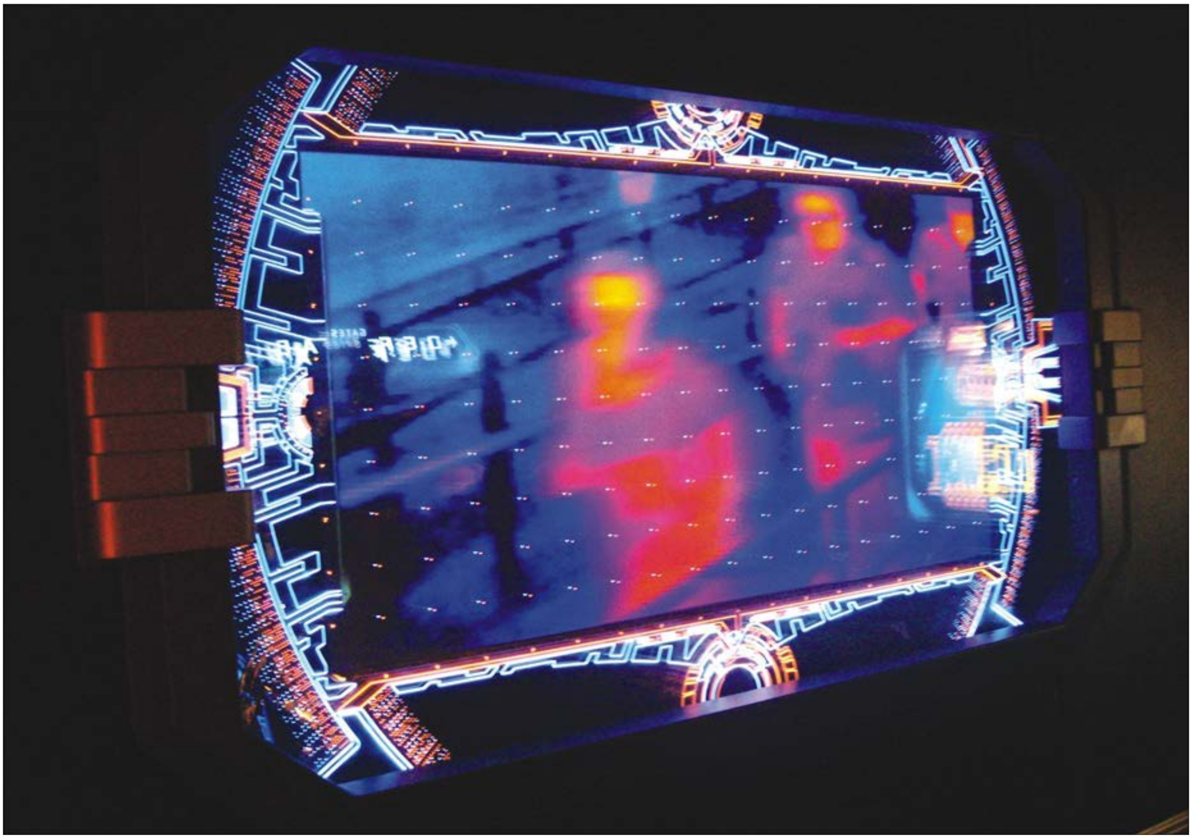

International Journal of

Thermal and Fluid Sciences

ISSN: 2225-3556

science alert

International Journal of Thermal and Fluid Sciences 1 (1): 1-10, 2012
ISSN 2225-3556 / DOI: 10.3923/ijtfs.2012.1.10

Effect of Convergent Walls on Energy Dissipation in Stilling Basin by Physical Modeling

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ABSTRACT

Energy dissipaters are usually used for release of energy at the downstream outlet of the spillway. Stilling basins are the most important type of these structures. Baffle piers and sills are used in implicit basins for decreasing hydraulic jump length and economic costs. Researches illustrated that the effect of mentioned components on decreasing of hydraulic jump length depend on basin dimensions, height and location of blocks and spacing between them. In this research the effect of geometric-hydraulic parameters on energy dissipation and hydraulic jump location have been experimented by change in baffle piers and end sill structures and convergence of walls in different discharges. To reach this goal, physical model of Nazloochay dam with 1:40 scale was constructed. Experiments were done in different cases: separate blocks with different dimensions, the effect of stepped surface instead of end sill and convergence of walls at the end of basin in 5, 7.5,10, 12.5 degrees. With discharge variation in control section of river in each experiment, the values of depth, velocity and static pressure in basin were measured. According to results application of these steps instead of end sill blocks at the end of stilling basin was not successful on stabilize the hydraulic jump in the basin specially in large discharges. But in the case of converged walls in all experimented degrees, submerged hydraulic jump formed. Convergence also has positive effect on energy dissipation and efficiency of hydraulic jump, 5 degree of convergence has the best operation.

Key words: Stilling basin, hydraulic jump, energy dissipator, convergent wall

INTRODUCTION

Dissipation of kinetic energy generated at the base of a spillway is essential for bringing the flow into the downstream river to the normal condition in as short of a distance as possible. This is necessary not only to protect the riverbed and banks from erosion but also to ensure that the dam itself and adjoining structures like powerhouse, canal, etc. are not undermined by the high velocity turbulent flow.

Stilling basins include horizontal or sloping aprons equipped with chute blocks, baffle piers and end sills are the most common type of energy dissipaters. These structures affects up to 60% dissipation of the energy entering the basin depending of the Froude Number of the flow. Different type of basins have been studied by USBR and its performance has been classified (Peterka, 1983). But in large dams because of special conditions, these mentioned samples for stilling basins were not secure. For example according to the studies carried out in water research institute, in Masjed Soleiman dam, the stilling basin was adjacent to powerhouse outlet so the stilling basin walls were not continued to the end and have been performed in overflow condition. Furthermore the velocity and Froude Number were widely larger than global recommended values. By construction and study of physical models we can optimize the length, dimensions, location of baffle piers and chute blocks in stilling basin and degree of protection needed for tail water in different flood passages and then select the optimized arrangements of these elements in design. Extensive works on different parameters in physical models of stilling basin has been done. Some of these relevant experiences are implied in the following:

Posey and Hsing (1938) studied the effect of lateral slope on hydraulic jump length in trapezoidal basins. This experiment was conducted in a model with variable slope between 0.5:1-2:1 and stated that, when lateral slope decreased, the length of the jump increased compared with rectangular channel. Wanoschek and Hager (1989) by experimental investigation implied that for trapezoidal channel with 1:1 lateral slope in comparison with rectangular channel, depth ratio decreased and the length of jump increased. Omid (1996) studied hydraulic jumps in trapezoidal stilling basins and showed that compared with rectangular basins for decreasing lateral slope, relative length of jump and dissipated energy increases.

Complication of converged or diverged hydraulic jump relations compared with normal jump is a result of existing lateral force in momentum equation. Arbhabhirama and Albella (1971) investigated hydraulic jump in diverged rectangular channel in 0 to 13 degrees of diversion and showed that diversion causes increasing in relative energy dissipation and decreasing in depth ratio and jump length. Esmaeeli varaki (2003) investigated diverged hydraulic jump in rectangular channel with 0.5×9×0.6 meter (width×length×depth) dimensions for 0.5:1, 1:1, 1.5:1 lateral slope, 5 and 7 degrees of divergence and 3 to 9 Froude number. According to the results in this trapezoidal sections decreasing in degree of diversion for each lateral slope compared with direct trapezoidal section(i.e., lateral slope = 0), decreases depth ratio and jump length and increases the percent of relative energy dissipation.

Experimental studies shows that using the new roughened bed, the length of the basin can be decrease as low as 40% of the regular basins (Bejestan and Neisi, 2009).

Ezizah *et al.* (2012) have performed to investigate the effect of change of intensity and roughness length parameters on the hydraulic jump length.

Analysis of experimental data shows that the Froude number in smooth bed hydraulic jump decreases the conjugate depth 20% and the hydraulic jump length 50% (Izadjoo and Shafai-Bejestan, 2007).

Rizi *et al.* (2006) said that the discharge variation as a boundary condition for moving hydraulic jump parameter could reliably be determined based on time independent relationships.

According to performed researches, there is no systematic experimental study for investigate the effect of convergence on hydraulic jump operation and because of complication in flow pattern in this cases, this research investigated the effect of convergence of stilling basin walls on energy dissipation condition and jump formation in stilling basin.

MODEL AND TEST EQUIPMENT

Nazloochay earthfill dam with 100 m high is constructing in north-west of Orumieh. The designed stilling basin for dam was a II type of USBR for probable maximum flood of 2270 cm.

Thus with these conditions (i.e., height of dam and type of stilling basin), this case selected for experiments and hydraulic model was constructed. The following model includes three linked parts:

- Upstream tank
- Flood discharge system:

    - Approach canal
    - Free ogee spillway
    - Converged chute
    - Stilling basin

- Downstream tank with (6.1×7.65×1.25 m, height×length×width) dimensions

With respect to thickness of water layer on spillway for preventing viscose effects and surface tension and laboratory limitations, 1:40 model scale was selected. Regulated amount of water pumped into model and its discharge measured with rectangular weir setup downstream. For regulating water level the sluice gate used at the end of canal in model.

The length and width of stilling basin in prototype are 43 and 30 m. Stilling basin model and other parts of it such as chute constructed of transparent plexiglas and baffle piers was made of wood covered with oily color. The inception of canal (i.e., after spillway) with 21 m length in prototype connected from stilling basin bed to river bed with 3:1 (horizontal: vertical) adverse slope. Bed level of basin is 1396 masl and river bed level is 1403 masl. Topographic surface constructed up to 1415 masl level based on map. The upper level of stilling basin walls is 1411 masl (Fig. 1-3).

Fig. 1: Physical model layout

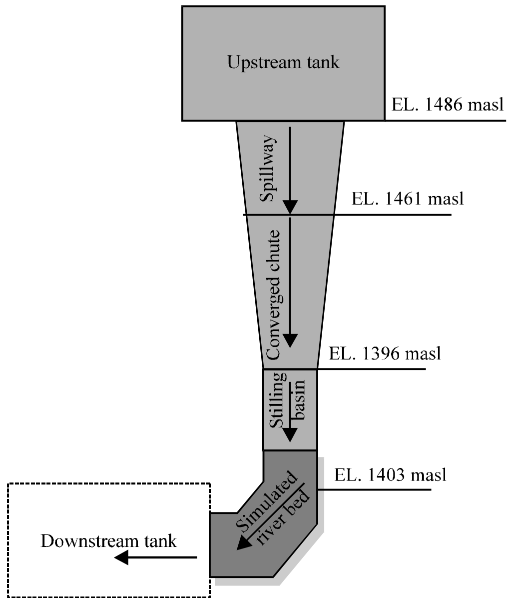
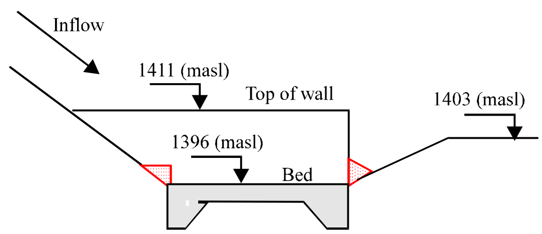


Fig. 2: Schematic plan of model



Description	Chute	Stilling basin	Riprap	River bed
Length (m)	104.11	43.0	21.0	... .

Fig. 3: Stilling basin cross section

Test procedure: According to project hydrologic studies, design flood of stilling basin is 500 cm with return period of 1000 year. Experiments were done for six discharges as summarized in Table 1 for surveying the effect of discharge. For each discharge, the values of depth, velocity and static pressure in basin sections were measured as defined in Table 2 and 3 and Fig. 4. Depth measured with Eshel. Because of flow fluctuation in basin measuring accuracy in model was ±5 mm. Velocity measured with micro mulline with ±1 m sec^{-1} accuracy in model. Also hydraulic jump type and location, situation of return flow and submergence of basin walls were investigated in each discharge for study the effect of variety of discharge on hydraulic parameters.

RESULT ANALYSIS

Nazloochay dam stilling basin had been designed as a II type USBR standard model according to project condition (Fig. 5a). Construction of physical model and perform experiments showed that this stilling basin cannot dissipate the energy safe and sufficiently, in

Table 1: Range of discharges

Prototype discharge (m^3 sec^{-1})	300	500	830	120	1800	2270
Model discharge (L sec^{-1})	30	49	82	119	178	224
Probability level	Less than design flow	1000 year	10000 year	-	-	PMF

Table 2: Location of sections in stilling basin

Section name	N	O	P	Q
Distance about spillway head in prototype(m)	277.6	285	300	315
Distance about spillway head in model(m)	6.94	7.13	7.50	7.88

Table 3: Location of bed piezometers

No. of piezometer	1	2	3	4	5	6	7
Distance about spillway head prototype (m)	285	290	295	300	305	310	315
Distance about spillway head in model (m)	7.13	7.25	7.38	7.50	7.62	7.75	7.88

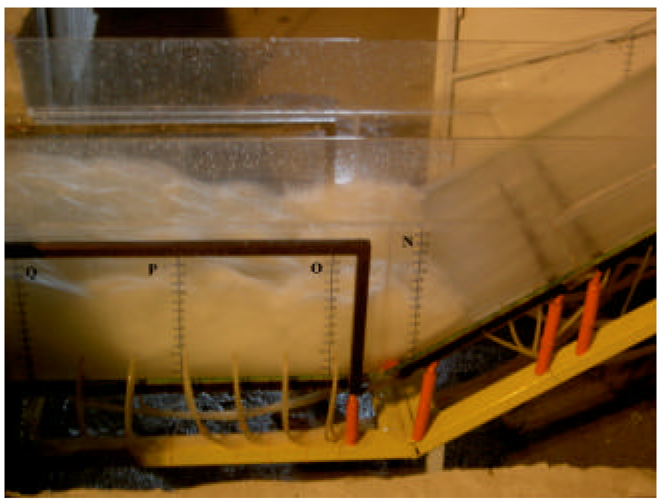


Fig. 4: Stilling basin sections for depth, velocity and static pressure measuring

some points the static pressure were negative, so in first change in basin design, the inclined end sill removed by three steps (Fig. 5b) for increasing tail water depth.

Although, this change had been done for stabilizing jump in basin but there are serious problems in basin operation especially in large discharges, yet. In such condition hydraulic jump move downstream and the flow left basin with high velocity, so caused erosion downstream of stilling basin like a ski jump bucket.

Thus for increasing depth ratio and stabilize jump in basin we need other preparation, so in this research the effect of the convergence of stilling basin walls and submergence caused by it, on hydraulic jump properties, energy dissipation and tail water condition has been investigated. Experiment has been done for 5, 7.5, 10, 12.5 degree of convergence of stilling basin walls. The converged walls were installed symmetrically in stilling basin as shown in Fig. 5c and 6.

Depth: The effect of convergence of walls on depth variation for 82 L sec^{-1} discharge in various sections has been showed in Fig. 7. According to diagram with converged walls has been increased

Fig. 5(a-c): Stilling basin arrangements

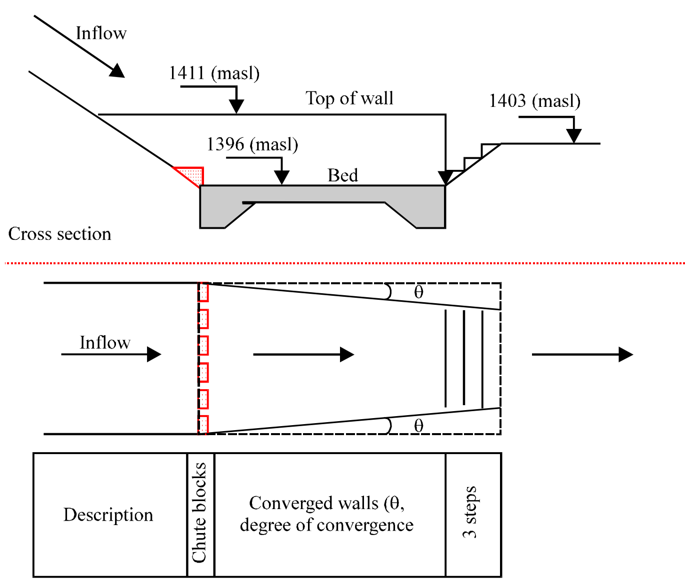


Fig. 6: Converged walls stilling basin (schematic plan and cross section)

in all sections compared with parallel walls. For each degree of convergence by increasing discharge, minimum depth decreases in measuring section and maximum depth increases, because by increasing discharge, hydraulic jump moves downstream relative to initial measuring section (Fig. 8).

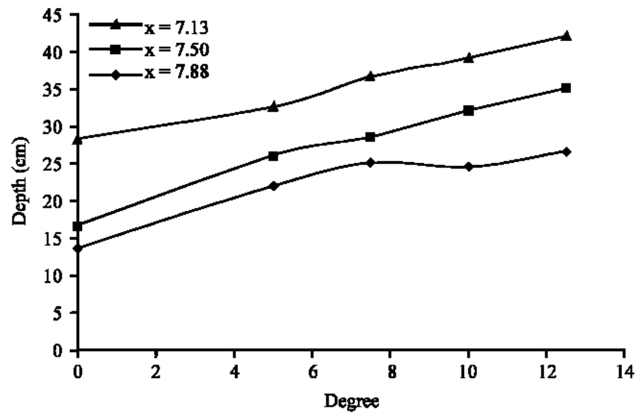


Fig. 7: Depth variation for 82 L sec^{-1} discharge in various sections and degrees

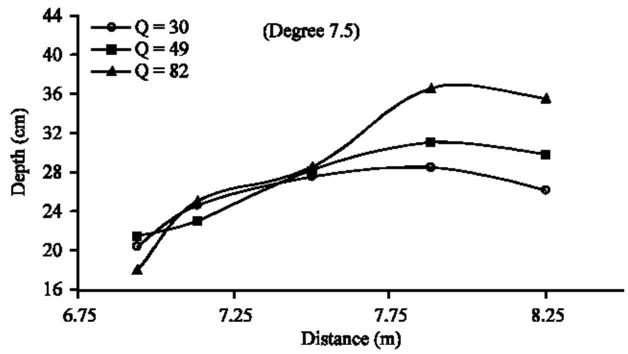


Fig. 8: Depth variation for 7.5 degree of convergence and various discharges

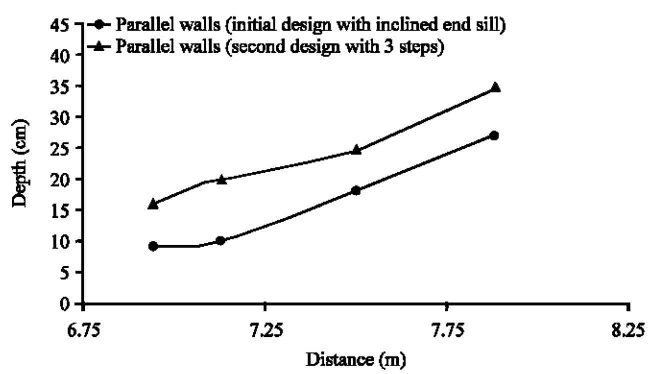


Fig. 9: Surface profile in 82 L sec^{-1} discharge in parallel walls stilling basin

Figure 9 and 10 which show the water surface profile in 82 L sec^{-1} discharge in parallel and converged walls condition, certify this result also. While it is observed that for parallel walls condition the water surface profile is concave which is showing free hydraulic jump and for parallel walls condition, the water surface profile is convex and hydraulic jump is submerged (Fig. 9 and 10). In this case no negative static pressure was observed.

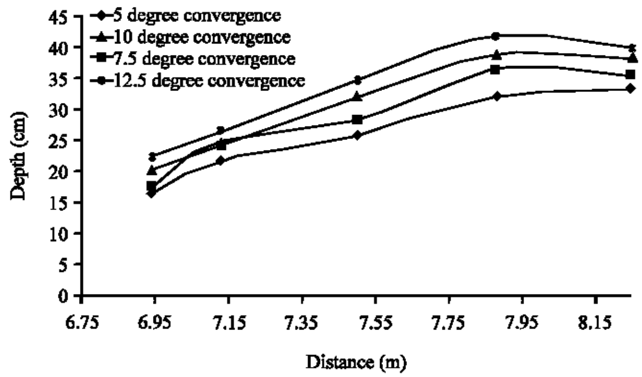


Fig. 10: Surface profile in 82 L sec^{-1} discharge in converged walls stilling basin

Fig. 11: Flow condition for 178 L sec^{-1} discharge (parallel walls)

Fig. 12: Flow condition for 178 L sec^{-1} discharge (converged walls, 10 degree of convergence)

Velocity: The velocity was measured in four sections (N,O,P,Q) as described above in 20 and 80 percent of depth from surface. Therefore the mean velocity was calculated by averaging two measurements. The velocity variation for 82 L sec^{-1} discharge has been showed in Fig. 13 by the effect of converged walls in stilling basin on water flow (Fig. 12), the velocity quantity in ending section (x = 7.88 m), has been decreased compared with parallel walls condition (Fig. 11). So in this

Table 4: Calculated efficiency in various conditions

	Discharge (L sec^{-1})		
Walls condition	30	49	82
Parallel walls	72.5	58.6	33.3
5 degree of convergence	83.1	82.1	78.5
7.5 degree of convergence	83.3	83.7	47.3
10 degree of convergence	85.2	83.8	51.7
12.5 degree of convergence	85.3	64.4	62.3

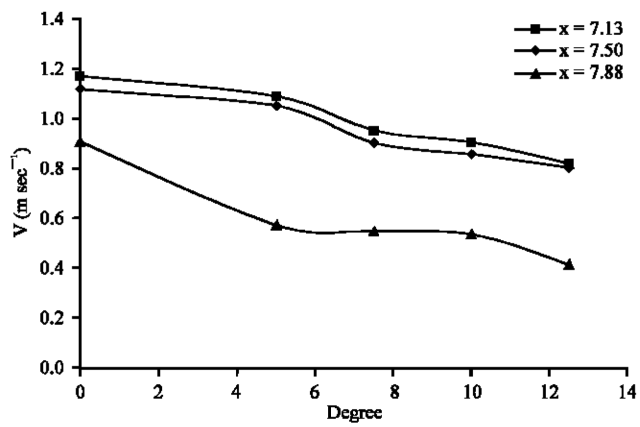


Fig. 13: Velocity variation for 82 L sec^{-1} discharge in sections

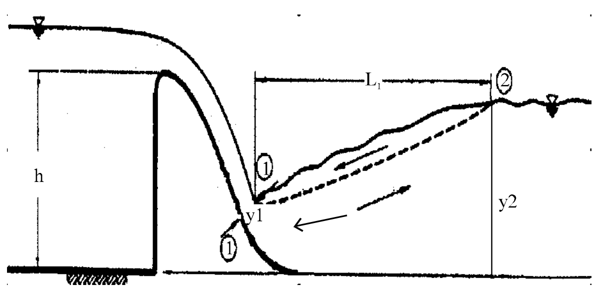


Fig. 14: Location of measuring y1, y2

case, stilling basin has been transformed shallow depth flow with high velocity of entrance (at x = 7.13 m), to a deep low velocity flow in the ending section(at x = 7.88 m). Therefore, stilling basin has good operation in energy dissipation and causes less erosion downstream.

Efficiency: Hydraulic jump operation efficiency were calculated by equations 1-3 in all experiment conditions (parallel and converged walls) and has been shown in Table 4. Initial depth of jump (y1) has been measured on sections while surface roller is formed and conjugate depth (y2) has been measured at the end of surface roller as shown in Fig. 14. According to results, hydraulic jump operation in converged wall stilling basin is better than parallel wall basins and the effect of convergence increases by increasing discharge. The variation of efficiency (especially in 82 L sec^{-1} discharge) is not affected by variation of degree of convergence and so 5 degree of convergence has the best operation.

CONCLUSION

For large dams according to special conditions, we cannot design standard stilling basins without physical modeling.

Nazloochay dam stilling basin was a II type USBR standard basin that had not good performance. So its arrangement was changed by physical modeling and its end sill removed by three steps. Application of three steps instead of end sill blocks at the end of stilling basin was not successful on stabilize the hydraulic jump in the basin specially in large discharges thus converged walls were installed in basin that leads to below results:

- For each degree of convergence by increasing discharge, minimum depth decreases in measuring section and maximum depth increases, because by increasing discharge, hydraulic jump moves downstream relative to initial measuring section in all experimented degrees, submerged hydraulic jump formed, so downstream erosion will be decreased
- Convergence has positive effect on energy dissipation and efficiency of hydraulic jump and 5 degree of convergence has the best operation

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