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Numerical Study of Flow Patterns in Stilling Basin with Sinusoidal Bed using Flow 3D Model

M. Tabatabai, M. Heidarnejad, A. Bordbar

Department of irrigation, Khouzestan Science and Research Branch, Islamic Azad University , Ahvaz, Iran .

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ABSTRACT

Due to the importance of stilling basins blocks and the significant impact of their shape and dimensions on energy dissipation, and since more studies have been conducted on less on the effects of sinusoidal characteristics of hydraulic jump and stilling basins and the objective of this study is to integrated blocks on characteristics of hydraulic jump, analyze the effect of sinusoidal blocks height on hydraulic jump length using Flow-3 D model which is robust program in simulation of 2D and 3D turbulent water. According the length of to the results, we can conclude as the Froude number of flow increases, so that four to five first blocks have ,both roller zone and hydraulic jump also increases little effect on the depreciation of output flow. As the height of blocks increases, the length of jump decreases and for the output flow from the gate for t/s =0.75 and 0.25, the length of roller zone is decreased by 40 to 50 cm. As the height of the block or the ratio of height to distance for sinusoidal block increases, hydraulic jump and full energy dissipation for output flow jet from the gate occur at a distance shorter than for blocks which have a smaller height.

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INTRODUCTION

Stilling basin or water jump basin is a short segment of a floored channel constructed at the end of a spillway or any other structure that generates supercritical flow in order to form a hydraulic jump in the basin. In this case, the supercritical flow, before reaching the non-floored parts of the river, turns to sub-critical flow and the great energy it has, is reduced; therefore, possible damages are avoided. The Jump occurs in a rectangular, horizontal and wide channel with a flat floor is called the classical hydraulic jump. To increase the efficiency of stilling basins and to reduce the length of the hydraulic jump, rough beds are usually used for basins. The rough bed can be made as stile, sinusoidal, trapezoidal, triangular, rectangular integrated waves within the channel. Hydraulic jump is a phenomenon that can lead to energy dissipation downstream of hydraulic structures. To increase the efficiency of stilling basins and to reduce the length of hydraulic jump, rough beds are usually used for basins. Stilling basins are appropriate places to create and to control hydraulic jumps. Blocks within the basin make jumps stable in the basin and dissipate the kinetic energy in a hydraulic jump resulting in increased efficiency of stilling basins. Therefore, this study is a numerical study of the effect of three different heights for integrated sinusoidal rough beds on characteristics of the hydraulic jump through applying different discharge rates and using advanced computational models for fluid dynamics such as Flow-3D. It seems the current study has achieved the desired results in this context.

Hook reported big jump and photography of them reported and Drummond presented a simple procedure. Bakhmutov and Matzgeh proposed dimensionless profiles of water level and also experimental data for corresponding depth (CLA) and jump length. The third study was conducted on designing by Scobbie. Moore studied the condition of jump generation at the bottom of the slope breaker as well as various forms of jumps and surface profiles.

The first mathematical model of a hydraulic jump was proposed by Russ, Narayan, Mac Krokodyl and Khalifa, Romadson and Sondson, Chaudery and the change of the supercritical flow to subcritical flow was simulated using Bosnisk type equation. Otsu et al. failed to find the effect of input flow on the corresponding depth, jump length and the maximum velocity but studied the effect of the increased boundary on jump length.

Corresponding Author: M. Tabatabai, Department of irrigation, Khouzestan Science and Research Branch, Islamic Azad University , Ahvaz, Iran.

Their study is important since they showed that the classical hydraulic jump is a certain type of submerged jump. The fourth period of studies on hydraulic jump ended by a review by Mac Krokodyl [1].

Studies conducted in recent years by researchers such as Eid and Rajaratnam (2002), Carlo and Ferro (2004), Pagliara et al. (2008), all suggest that artificial roughness under a water jet can significantly reduce the hydraulic parameters of the jump including the length of the jump and consequently the length of the basin.

Izadjou and Shafaei B., (2004), investigated the effect of wavy bed on jump length and under pressure fluctuations in stilling basins in the form of hydraulic jump. In this context, they measured the values of the hydrodynamic under-pressure fluctuations in different roughness and for various hydraulic conditions as a Froude number ranging between 3.7 and 12.9. According to the above discussion, it is obvious that not many studies have been conducted on criteria of designing the slab thickness and in mentioned studies, the effect of hydrodynamic and lifting forces on flat beds have been examined.

Bakhtiari et al (2008), in a study investigated of the effect of divergence walls in rectangular stilling basins began on characteristics of jumps and thus stilling basins. They studied 5 divergence angles. The results obtained in this research indicate the higher jump efficiency at greater angles; therefore the basin is more economical at greater angles.

Neisi and Shafaei B. (2009) found that the rough bed reduces the flow velocity and the extension of the boundary layer is quite different for different roughness.

Ravar et al. (2010), in an experimental study examined the effect of the arrangement and the height of integrated vertical trapezoidal roughness on the hydraulic jump characteristics. Comparing the results obtained in this study with results obtained for the hydraulic jump on flat beds shows that the tail-water depth and the length of hydraulic jump are considerably reduced over the rough beds compared to the flat beds.

Gohari and Farhood (2009) studied the characteristics of the hydraulic jump on beds with rectangular strip roughness in Froude numbers ranging from 3 to 10 and observed that the secondary depth of the jump on rough surfaces has declined substantially compared to flat surfaces. They also observed that this reduction is intensified when the distance between the rough surfaces is increased.

Abbasi et al. (2012) studied the energy dissipation in stepped spillway applying the various geometrical changes. In this study, to identify the effect of various parameters on energy dissipation in simple stepped spillways, the Flow-3D numerical model was used. The results showed that as the flow discharge increases, the energy dissipation is reduced and with a constant barrier height, as the number of stairs increases, the energy dissipation can be reduced.

MATERIALS AND METHODS

Hydraulic Jump:

In a classical hydraulic jump, characteristics of the input flow are indicated by the depth of flow (y_1), and average velocity $\left(v_1 = \frac{Q}{By_1} \right)$ as follows:

$$Fr_1 = \frac{V_1}{\left(g_1 \; y_1\right)^{\frac{1}{2}}} \tag{1}$$

Where Q represents discharge and B is the width of a rectangular channel.

Since in a hydraulic jump, the energy loss is unknown, the energy equation cannot be used to find the ratio of primary to secondary depth. Therefore, due to the short length of the hydraulic jump, and assuming the slope equal to zero, the effects of frictional force, the weight of water, and the force of air resistance can be ignored. So we can use the momentum equation as equation (2) for the sections before and after the jump.

$$F = \bar{y}A + \frac{Q^2}{gA} \tag{2}$$

In water jumps, two different lengths are generally considered: length of rotation (L_r), which is the distance between the initiation of jump to the last roller waves; and length of jump (L_J), which is the distance between the start point of the jump to a point on the water surface immediately after the last roller wave; therefore, the height of this point tumble is equal to the height of tail-water.

Energy loss in the hydraulic jump is due to particles turbulence and flow lines collisions resulting in the conversion of the kinetic energy created by flow rate, to the thermal energy. This phenomenon uses the hydraulic jump as a way to depreciate the energy. Therefore, one of the most important issues in the evaluation of jump is the rate of change of this parameter.

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Energy loss (E_L) is the rate of energy loss from the primary section to the secondary section of the jump due to turbulence in the flow. To calculate energy loss in the jump, we can calculate with the energy difference between the two sections after applying the energy equation for sections before and after the jump.

Simulations Method:

Flow-3D is multilateral program compatible with complex flow conditions for 2D and 3D modeling. This program is specific to computational fluid dynamics (CFD) and is presented by Flow Science. Equations are solved in this program based on finite volume method.

Flow-3D solves equations of fluid motion using finite volume approximations. The flow environment is classified to nets with tubular cells and for each cell, there are values of dependent parameters. In other words, all variables are calculated at the center of the cell, except the velocity which is calculated at the center of the cell faces.

To model the laboratory flume, both Flow-3D and AutoCAD were used. The tests were conducted on a channel with length, width and height equal to 12, 3.0 and 4.0, respectively. Sinusoidal bumps have heights of 10, 20 and 30 mm and a wave length is 40 mm. Froude numbers in this study range between 4.6 and 12.2.

Since the gate edge and sinusoidal roughness are of great importance, to mesh the model, a large number of grid cells were used. And since increasing the number of mesh cells directly affects the time of program running, we tried to achieve an optimal mesh size and number of cells to consider both time and accuracy. It should be noted that the mesh divisions have no effect on flow lines and are only used for mesh.

Fig. 1: Meshed model in Flow-3D.

Data and Discussion:

Examining the effect of changes in hydraulic conditions on the length of roller zone in a stilling basin with integrated sinusoidal blocks:

Figures 2, 3 and 4, respectively indicating that the effect of the initial Froude numbers 4.2, 7.6 and 11, show changes in flow velocity distribution within the basin and characteristics of the hydraulic jump in constant blocks height and different Froude numbers in order to make it possible to follow the effect of changing hydraulic conditions on the characteristics of the hydraulic jump in the basin with sinus block.

These results indicate that as the Froude number increases from 4.2 to 11, the length of roller zone and the hydraulic jump also increase. Therefore, when the Froude number is the maximum, the longest jump and roller zone are observed and the hydraulic jump energy is dissipated at a distance longer than small Froude numbers. Reversely, when applying the minimum Froude number, the shortest roller zone and turbulence are observed. Thus, when applying the large Froude numbers and flow discharges, in order to dissipate the energy more, the size and height of the blocks must be changed or the length of the stilling basin must be increased to eventually reach an economic plan.

As the Froude number is increased from 4.2 to 11, which are respectively the minimum and maximum initial Froude numbers in this study, the relative length of roller zone is also increased 30-40%. When applying the Froude number of 11, the wave generated from the hydraulic jump will to the end of the basin and the water jet leaving the gate will continue about 2 meters; therefore, four to five first blocks have little effect on the output flow dissipation.

According to the output images and simulation results, it can be concluded that as the Froude number increases, the length of roller zone and hydraulic jump increases, i.e. complete energy dissipation occurs at a greater length.

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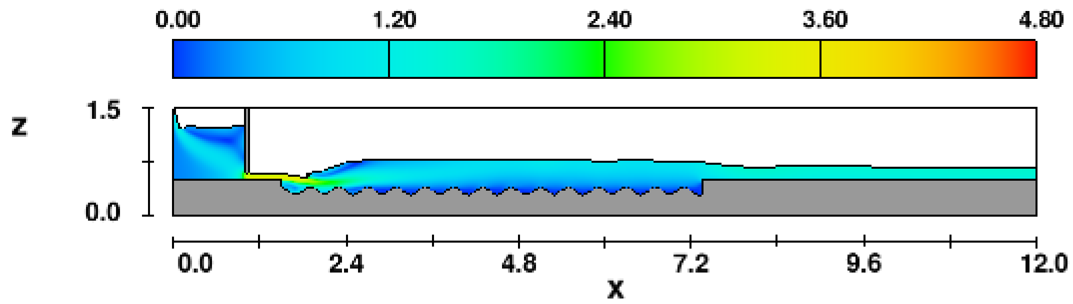

Fig. 2: The distribution of hydraulic jump velocity in a stilling basin with sinus blocks and Froude number equal to 4.2

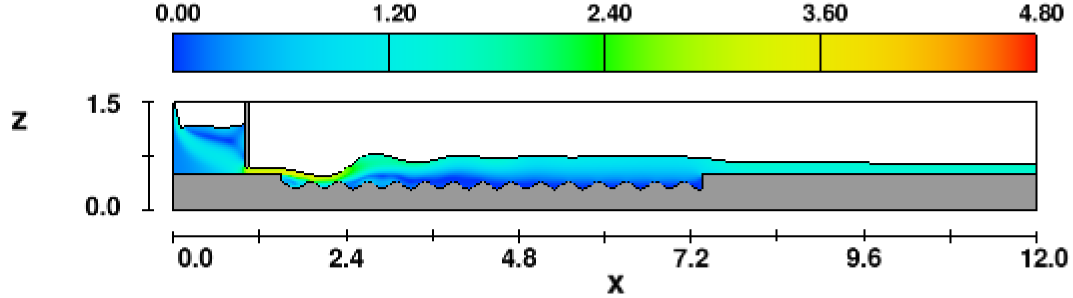

Fig. 3: The distribution of hydraulic jump velocity in a stilling basin with sinus blocks and Froude number equal to 7.6

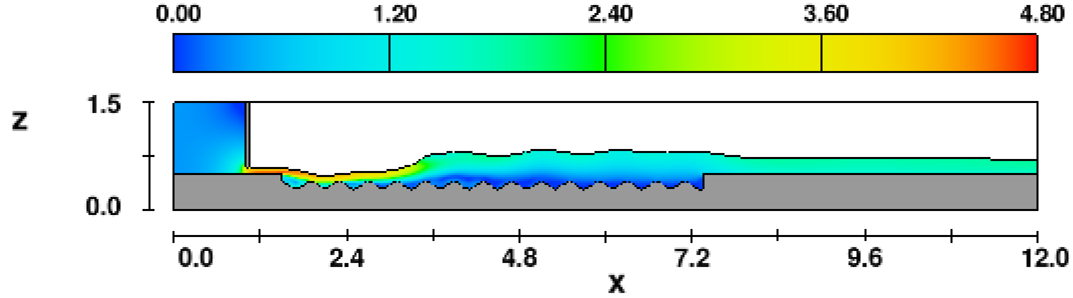

Fig. 4: The distribution of hydraulic jump velocity in a stilling basin with sinus blocks and Froude number equal to 11

Examining the effect of changing the height of the sinus blocks in stilling basin on the length of roller zone:

Figure (5), (6) and (7) represents the effects of considering different heights for sinus block or different ratio of sinus block height to spacing on velocity distribution and characteristics of the hydraulic jump in the stilling basin. To examine the changes in hydraulic jumps characteristics, a constant Froude number and different blocks height including 10, 20 and 30 mm are considered in order to observe the effect of changing the height of the block on the jump characteristics in a basin with sinus blocks.

Results obtained by comparing 2D color images and longitudinal profiles of velocity distribution indicate that as the height of blocks increases or the ratio of the height of the blocks to the distance is decreased, the length of roller zone and the hydraulic jump is decreased. When applying the maximum height considered in this study for the blocks, we observe that the jump is swamp immediately after the flow quit the gate and the output flow is quickly dissipated. As the height of blocks increases, the length of jump decreases from t/s =0.75 and 0.25and for the output flow from the gate, the length of roller zone is decreased by 40 to 50 cm.

Based on the output images obtained from numerical simulations, the relative length of the roller zone decreases by 30 to 35% as the block height increases or the ratio of height to distances of blocks decreases from t/s =0.75 and 0.25.

According to output images and simulation results, it can be concluded that as the height of the blocks or the ratio of height to distances for sinus blocks increases, both the hydraulic jump and the complete energy dissipation of the jet outflow from the gate occur at a distance shorter than the condition in which the height of the block is less.

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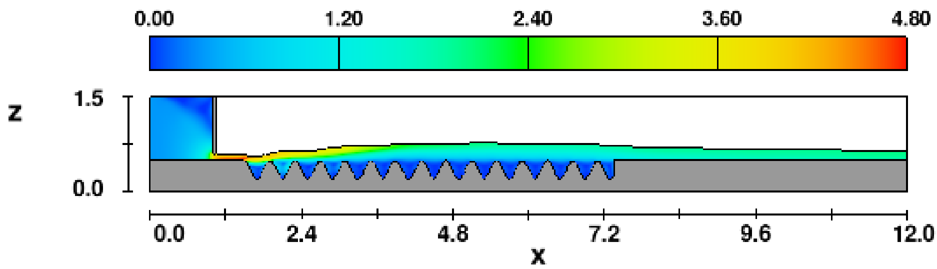

Fig. 5: The distribution of hydraulic jump velocity in a stilling basin with sinus block and t/s = 0.75

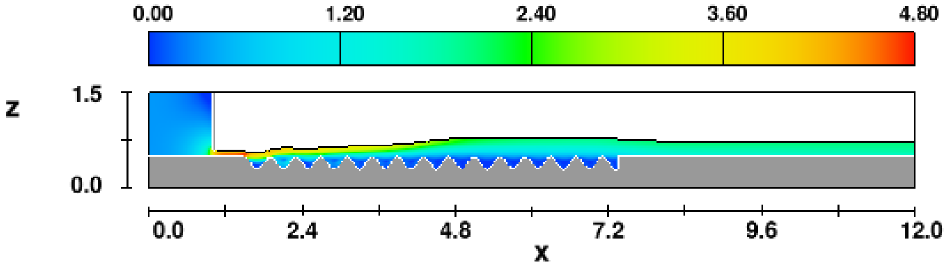

Fig. 6: The distribution of hydraulic jump velocity in a stilling basin with sinus block and t/s = 0.5

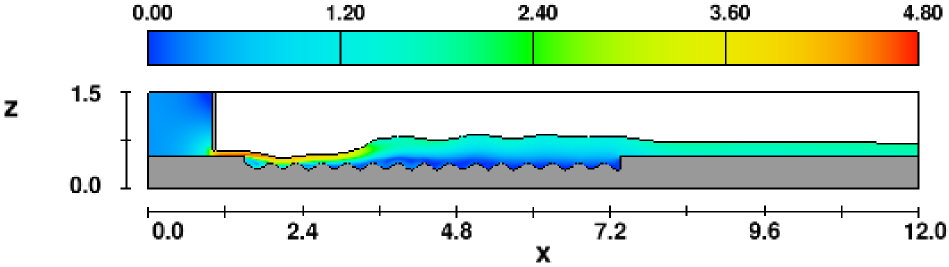

Fig. 7: The distribution of hydraulic jump velocity in a stilling basin with sinus block and t/s = 0.25

A 3D display of velocity distribution and flow pattern in a stilling basin with a sinus block:

In experimental studies, using X-rays photography of the longitudinal profile of the jump and digitalizing the photos using Grapher, information on the profile of the water surface in the jump is recorded and this is while the outputs of Flow-3D display many parameters and characteristics of the hydraulic jump as color images with high resolution.

Figure 8 shows the 3D image of velocity distribution and the flow pattern which are the output of the program. In this image, the effect of sinus block on the formed hydraulic jump and the energy dissipation is shown. The profile of the formed water surface is also displayed properly in the image.

In this study, to simulate the turbulent flow and hydraulic jump formed in basins with sinusoidal blocks, the Two-equation (k-e) model was used and according to the results, the simulation of the turbulent flow leaving the gate and hydraulic jump instilling basins with sinus block has an appropriate accuracy.

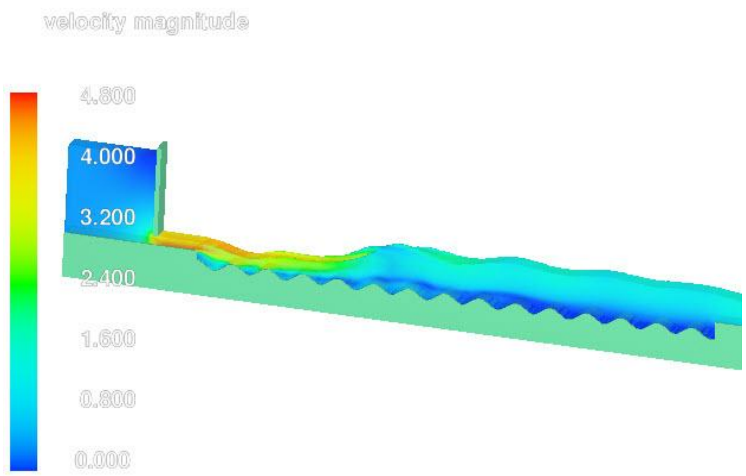

Fig. 8: 3D image of the flow passing through the gate and forming the hydraulic jump

Conclusions:

As the Froude number increases, the length of roller zone and the hydraulic jump increases, i.e. complete energy dissipation occurs at a longer distance and as the Froude number is increased from 4.2 to 11, which are respectively the minimum and maximum initial Froude numbers in this study, the relative length of roller zone is also increased 30-40%. When applying the Froude number of 11, the wave generated from the hydraulic jump will to the end of the basin and the water jet leaving the gate will continue about 2 meters; therefore, four to five first blocks have little effect on the output flow dissipation. As the height of blocks increases, the length of jump decreases and for the output flow from the gate for t/s =0.75 and 0.25, the length of roller zone is decreased by 40 to 50 cm. the relative length of the roller zone decreases by 30 to 35% as the block height increases or the ratio of height to distances of blocks decreases from t/s =0.75 and 0.25. As the height of the block or the ratio of height to distance for sinusoidal block increases, hydraulic jump and full energy dissipation for output flow jet from the gate occur at a distance shorter than for blocks which have a smaller height. In this study, the Two-equation (k-e) model has an appropriate accuracy in the simulation of the turbulent flow leaving the gate and hydraulic jump instilling basins with sinus block.

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