Effects of continuous triangular roughnesses on the hydraulic jump characteristics in horizontal Stilling basin

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Abstract-A hydraulic jump is a surprising phenomenon in the science of hydraulics which dissipates hydrokinetic energy. Hydraulic structures like stilling basin frequently use this important characteristic of the hydraulic jump in order to dissipate energy in downstream of spillways, gates and torrents. Since dimensions of these structures are directly dependent on characteristics of the hydraulic jump therefore to make them economical many wide surveys have been conducted on characteristics of hydraulic jump and how to control them or minimize their dimensions. For example in the recent years it has been suggested that continuous roughness of the Stilling basin could be effective in reducing jump dimensions. The present study has been performed by considering this assumption and it is tried to determine level and type of this effect showed that roughnesses decrease jump length to moderate size of 57% and provide about 20% decrease in secondary depth of jump than classic type. This decrease can be caused by increase in flow turbulency level between roughnesses that causes approximately 13-fold increase in shear stress.

Key words: hydraulic jump, rough bed, relative conjugate depth, jump length, roller length energy loss

Introduction
In designing hydraulic systems flow speed should not be more than acceptable level. High water velocity at an earthy channel or a natural river causes bed and channel wall erosion that may irreparable damages to the installments neighboring river. Often we meet very high hydrokinetic energy due to different reasons like high steep of the earthy channel floor or high energy difference between two sections or free water falling that inevitably we should design structures that dissipate additional hydrokinetic energy and decrease flow velocity significantly. In downstream of spillway in dams flow velocity and finally hydrokinetic energy increase severely in result of high height difference that if this energy is not decreased, floor erosion is revealed and a cavity is created in downstream of dam that in long term causes dam to be collapsed. So this high speed should be controlled in hydraulic systems. The structures that decrease flow energy and velocity to an acceptable level are called Energy Dissipator structures. In short, these structures are as follows:

Energy Dissipator structures in horizontal direction: In these structures that are often seen in downstream of spillway (ogee shape spillway), channels and at the end of drops, water energy is wasted as hydraulic jump and types of Stilling basin are of this type.
Rajaratnam is one of the first researchers that studied widely about the effect of hydraulic jump features on channels with rough bed. He showed that the roller length, jump length and secondary depth of jump are decreased significantly on rough bed than their corresponding values on flat bed.

Materials and methods

Targeted experiments were performed in a channel with a length, width and height of 8, 0.35, and 0.4 respectively in the hydraulic laboratory of Azad University of Yasouj. Some triangular roughnesses with a width of 35 cm were studied in three different spaces (12, 8, 4 = t) and in each height four different spaces between blocks are considered for incoming supercritical flow. Regarding roughnesses crest and upstream bed are on the same level, waves act like cavity and change in their height has not many effect on hydraulic jump characteristics. It was shown that compare to flat beds there is 15-fold shear force on rough beds so that generally 4 values were obtained for the roughnesses space-height ratio. s/t = 1, 0.5, 0.33). Created false floors were placed in channels in such a way that they placed in downstream of the ogee spillway and in 120cm space from spillway claw. In this case roughnesses act as some cavities in the floor of bed that create eddy flows and increase Reynolds shear stress at the floor. 96 experiments were performed in the range of Froude numbers ranging 5-12.5 with values 0.33 < t/s < 1. To create supercritical flow and first depths of jump a ogee spillway made of galvanize was installed at the beginning of channel and a sliding gate was installed at the end of the channel to turn the jump back and also a meter strip installed in body of the channel was used to measure length of the water jump and the roller.

Results and Discussion

Secondary depth of the hydraulic jump on the rough bed can be defined as follows:

\[ Y_2 = f_1(y_1, v_1, g, \rho, \nu, t, s) \]

Where s is roughnesses space, t is height of roughnesses, \( \nu \) is kinematic viscosity of the fluid, \( \rho \) intermediate density, g acceleration of gravity, and \( y_1 \) and \( v_1 \) are respectively depth and velocity of incoming supercritical flow.

Using Buckingham \( \pi \) theorem the relationship 2 is obtained:

\[ \frac{y_2}{y_1} = f_2(Fr_1, \frac{v_1}{\sqrt{gy_1}}, Re_1, \frac{v_1 y_1}{\nu}, \frac{t}{y_1}, \frac{s}{y_1}) \]

By considering water temperature about 19°C in this research the minimum Reynolds number provided in experiments equals 18995. So regarding turbulent flow, effect of the Reynolds number and viscosity can be disregarded and equation 3 is simplified as follows:

\[ \frac{y_2}{y_1} = f_3(Fr_1, \frac{t}{y_1}, \frac{s}{y_1}) \Rightarrow \frac{y_2}{y_1} = f_3(Fr_1, \frac{s}{t}) \]
Relationship between the relative conjugate depth \( \frac{y_2}{y_1} \) and \( Fr_1 \) for all experiments has been shown in the figure 4 and suggests that compared to flat bed the relative conjugate depth in the rough bed decreases significantly when the fraud number of upstream is increased. Relationship between \( y_2/y_1 \) and \( Fr_1 \) has been defined as parameter of depth decrease \( D = \left( \frac{y_2^* - y_2}{y_2^*} \right) \) to present level of secondary depth difference in the rough bed\( (y_2) \) and classic jump \( (y_2^*) \). Changes of \( D \) by \( Fr_1 \) in the figure 5 show that \( D \) is increased when fraud number of flow is increased that result from experiment of \( y_2^* \) rather \( y_1 \). Maximum amounts and average \( D \) parameter are 0.27 and 0.18 respectively.

![Figure 4](image4.png)
Figure 4- changes of relative conjugate depth against Fraud number in rough beds for all experiments

![Figure 5](image5.png)
Figure 5- changes of the depth decrease parameter against Fraud number

Hydraulic jump length and roller length
Changes of \( B \) length of the hydraulic jump dimension \( (L_J/Y_1) \) against \( Fr_1 \) have been showed for different heights and spaces of roughnesses and indicate that jump length decrease slightly when roughnesses space is increased. Increase in height of roughnesses decrease jump length and roller length. Minimum decrease is 57 and 39 percent respectively. The figure 5 shows the hydraulic jump relative length changes \( (L_J/y_2) \) against Fraud numbers of the incoming supercritical for all experiments on the rough bed and data obtained by USBR. As it's seen \( (L_J/y_2^*) \) amounts are relatively constant against Fraud numbers changes and is for all data about 3.75.

![Figure 6](image6.png)
Figure 6- Changes of the jump dimension B length against Fraud number in the rough beds

![Figure 7](image7.png)
Figure 7- changes of the B length of roller dimension against Fraud number in rough beds

Relative Energy loss
Energy loss \( (E_L) \) and relative energy loss \( (RL) \) in hydraulic jump is defined as:
\[ E_L = E_1 - E_2, \quad RL = E_1/E_1 \]
That \( E_1 \) and \( E_2 \) are as special energy height of the flow respectively at the beginning and end of hydraulic jump. Changes of relative energy loss (RL) against \( Fr_1 \) have been drawn in the figure 8. This figure shows that \( R_L \) amounts in the rough beds are larger than flat beds and this difference increase a little when Fraud number is increased. Maximum loss in the rough bed is about 81 percent that with regard to the figure 8 this amount is up to 6 percent higher than flat bed.

Figure 8- Changes of the relative energy loss against Fraud number in rough beds

The main reason of the secondary depth decrease in the hydraulic jump on the rough beds than flat beds is presence of additional shear stress. If \( F_t \) is total of bed shear forces on the horizontal surface aligned with the crest in the length of jump, so using momentum equation it can be stated:

\[
(P_2-P_1) + (M_2-M_1) = F_t \quad (4)
\]

That \( P \) and \( M \) are pressure and momentum amounts and indices1 and 2 are respectively marker of sections after and before the jump. Rajanatnam (10) defined in his research shear stress coefficient of bed

\[
(\varepsilon = Fr^2/2)
\]

Using this relationship and data obtained from performed experiments changes of the shear stress coefficient with \( Fr_1 \) have been drawn in the figure 12. Relationship between \( Fr_1 \) and \( \varepsilon \) can be estimated as equation 9:

\[
\varepsilon = 6 Fr_1 + 4.6 Fr^2_1 \quad 0.904 \quad (5)
\]

Rajaratnam (11) has obtained \( \varepsilon \) amount in the flat bed (per unit channel width) as a function of the upstream Fraud number that is presented below:

\[
-0.7 Fr_1 + 10.16 Fr_1^2 \varepsilon = (10)
\]

By comparing equations 9 and 10 it can be understood that \( \varepsilon \) amount in the hydraulic jump on triangular rough beds is 3.4-13 times more compared that amount in flat bed. Also increase in space and height of roughnesses increase amount of shear stress that this procedure becomes intense by increase in Fraud number.

Figure 9- shear stress Changes of the rough beds with Fraud number

**Conclusion**

- Relative conjugate depth amounts of the jump on rough bed \((Y_2/Y_1)\) are lower than that amounts on flat beds and this procedure becomes intense when Fraud number is increased. Change in roughnesses space and height is not very effective on \(Y_2/Y_1\).
- Percent of jump length decrease on the rough bed than flat bed \((T)\) changes between 17-57 percent.
- Roller length reduces up to 39% when space and height between roughnesses increase. Space has more effect on roller length decrease and Fraud number increase makes this procedure intense.
- Jump relative energy loss \((R_L = E_2/E_1)\) is increased by increase in first Fraud number in rough beds. Maximum energy loss in rough bed is about 85% and increase in energy loss is up to 10% more than flat bed.
- Roughnesses space and height change has not significant effect on the energy loss amount.
Maximum and minimum depth (D) decrease parameter in 5-12.5 range of Fraud numbers is respectively 0.18-0.27.

Shear stress coefficient of the floor for rough beds is 4.3-13 times more than flat beds. Increase in height and space between roughnesses increases shear stress of the floor.

Increase in dimension B amounts of the roughnesses space-height ratio (s/t) decrease slightly secondary depth, jump and roller length and shear stress of the floor. So of s/t amounts studied in this survey s/t=2 was selected as optimum ratio for roughnesses dimensions that has the most positive effect on the hydraulic jump characteristics.

References


