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ORIGINAL ARTICLE

Analysis amount of Pressure Fluctuation in negative step B-jump with rough bed

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ABSTRACT
Considerable portion of flowing water kinetic energy downstream many type of hydraulic structures, must be dissipate. This dissipation is for prevent channel bed erosion downstream of the structure from water energy. One of the most effective means of accomplishing such goal is to use a hydraulic jump type stilling basins. There are several different types of stilling basin which depending on the geometry of the channel boundaries. A negative step with abrupt drop is one of them. It can reduce the characteristics of the hydraulic jump. Four types of jump which can occur within this basin. One and most usable of this type of jump in such basins, is B-jump. Roughening of the basin bed also is an effective measure which decreases the characteristics of jump. In this study a stilling basin with a combination of bed roughness and negative step are studied experimentally and the pressure fluctuation through stilling basin was measured for B-jump type. From these data the negative and positive pressure fluctuations coefficients were calculated and compared with the previous studies which has been reported on classical jump and jump on smooth bed of negative step. The results show that amount of pressure fluctuation coefficients is less than smooth bed and this decrease is more than 90%. Also show that the roughness elements on the bed of basin can reduce the fluctuations value. Therefore they can reduce the possibility of basin bed cavitation.
Key Words: *Hydraulic jump, Stilling Basin, negative step, B-jump, Roughened Bed, hydrodynamic forces*

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INTRODUCTION

a stilling basin of hydraulic jump type with negative step is used to improve the jump characteristics and to ensure that the hydraulic jump will take place at proper location and will be under control. The hydraulic jump which occurs in wide rectangular horizontal channels with smooth bed (classical jump) and has been widely studied by Peterka [1], Rajaratnam [2], McCorquodale [3] and Hager [4]. Rjaratnam (1968) carried out the first systematic studies on hydraulic jumps over rough bed. He introduced a parameter called the relative roughness [5]:

$$K=K_e / y_1$$

In which k_e is the equivalent roughness element and y_1 is the initial depth of incoming jet above the rough surface. Rajaratnam (1968) had been shown that the length of the roller (L_r) and the length of jump (L_j) upon rough bed (in comparison to the same parameters in jumps upon smooth bed) would decrease significantly [5]. Figure 1 shows the definition of classic jump characteristics over rough bed.

Hughes and Flak (1984) also carried out experimental research on hydraulic jumps upon roughened bed [6]. They found that boundary layer roughness will definitely decrease the sub-critical depth and length of the jump and the extent of this decrease are related to the Froude number and relative roughness of the bed.

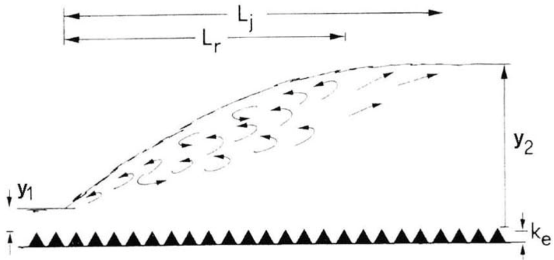


Fig 1. Hydraulic jump over uniform roughened bed

Mohammad Ali (1991) was performed a series of experiments upon uniform roughened bed using cubed elements and showed that the relative length of the jumps over rough bed in comparison to classical jumps varies from 27.4 to 67.4% [7]. Other studies by Gill [8], Hughes and Flack [6], Ead and Rajaratnam [9], Izadjoo and Shafai Bejestan [10] and Pagliara et all [11], proved that the roughness have remarkable effect on reducing the jump characteristics.

The first research of stilling basins with negative step has been reported by Moore and Morgan [12]. They classified four types of jump which can occur within the basin as shown in Figure 2.

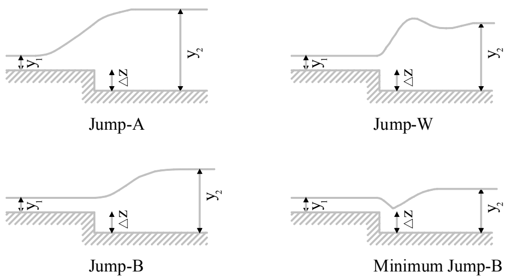


Fig 2.Four types of hydraulic in case of stilling basin with negative step (Moore and Morgan 1958)

Sharp (1974) investigated the characteristics of hydraulic jump on a negative step with rounded drop and comparing it with abrupt drop [13]. He showed that the sequent depth is reduced in round edge drop; the reduction depends on the degree of roundness. For higher Froude number, however the roundness caused to increase the sequent depth. Hager and Kawagoshi (1990) continued the researching on hydraulic jump in negative step [14]. They developed relation for predicting the sequent depth for jump on negative step with smooth bed.

The significance role of hydraulic jump bed pressure fluctuations on stilling basin design, was studied by Toso and Bowers [15], Fiorotto and Rinaldo [16] and Areminio et all [17]. Toso and Bowers (1988) measured pressure fluctuation on a hydraulic jump with smooth bed [15]. They showed that amount maximum and minimum of positive and negative pressure fluctuations (C_p+ and C_p-) along the jump, at first shows increasing and then decreasing. They use below equation for mean pressure fluctuations (C'_p):

$$C'_p = \frac{RMS}{\alpha \frac{v^2}{2g}} \qquad (1)$$

Where the RMS or standard deviation is measured in meters; α = a function of the inflow velocity profile (usually assumed equal to 1.0); V = the incident flow velocity; and g = the acceleration of gravity.

The study of Fiorotto and Rinaldo (1992) focused on developing an equation for designing the thickness of the slab (s) for classical jump stilling basin based on pressure fluctuations coefficients in the form of equation 2 [16].

$$s = \Omega\left(\frac{L_1}{y}, \frac{L_1}{I_1}, \frac{L_2}{I_2}\right)\left(Cp^+ + Cp^-\right)\frac{v^2}{2g}\frac{\gamma}{\gamma_c - \gamma} \qquad (2)$$

Where Ω= dimensionless coefficient related to the distribution of the pulsating pressure; C_p+ and C_p- =positive and negative pressure coefficients; $v^2/2g$ = kinetic energy head of the incident flow; γ and γ_c = specific weights of water and concrete, respectively. The p'_{max}+ and p'_{max}-are, respectively, the maximum and minimum measured pressure values. They are suggested to the c_p+ and c_p- coefficients measured by

$$\frac{\Delta p^+_{max}}{\gamma} = C^+_p \frac{v_1^2}{2g} \quad \text{And} \quad \frac{\Delta p^-_{max}}{\gamma} = C^-_p \frac{v_1^2}{2g} \qquad (3\text{ a,b})$$

Where ΔP = the pressure deviation from the mean in meters; they showed that investigation of hydrodynamic forces without studying the negative and positive fluctuations (C_p+ and C_p-) is useless. Areminio et al (2000) studies was conducted to measure the pressure fluctuation on a smooth bed of negative step stilling basin [17].In their research two types of step, rounded and abrupt drop, and for each types of drop, W and B-Jump, were studied. They showed that in negative step the value of C'_p, first will be increase and then when it reaches to the highest value it start to decrease. Also by measuring C_p+ and C_p- they showed that the value these coefficients for B-Jump is higher than the classic jump and therefore they concluded that the stilling basin with negative step requires a thicker slab than a classical smooth type of basin. Hassonizadeh and Shafai-Bajestan (2001) also reported pressure fluctuation on the bed of classical jump and found that both C_p+ and C_p- at any flow conditions along the jump, first will indicate increasing and after reaching the highest point will start to decrease [18]. They showed that fluctuations in center line of jump, was same as the fluctuations in left and right lines. This research was conducted to studying the pressure fluctuations distribution on a stilling basin with negative step and roughened bed.

MATERIALS AND METHODS

In order to reach to the main purpose of this study, a rectangular flume 80 cm wide, 70 cm deep and 15 m long were used. The side walls of the flume were made of glasses. Water was pumped from a storage tank to the head tank of the flume by a centrifugal pump. Cubed elements was made from hard plastic (see Fig.3) they installed on the flume bed in such a way that the crests of the cubes were at the same level as the upstream bed. (h_b=bed drop). The supercritical flow was produced by a sluice gate. Water entered the flume under this sluice gate with a streamlined lip, thereby producing a uniform supercritical flow depth with a thickness of y_1. The height of step was 4.5 cm and a tailgate was used to control the tail water depth in the flume. In all experiments, the tailgate was adjusted so that the jumps were formed B-jump (see Fig. 2). The discharges were measured by an ultra sound flow meter installed in inlet pipe with DN=300mm. Values of y_1 and V_1 were selected to achieve a range of the Froude number, from 3.03 to 5.86. The Reynolds number $R_1=V_1y_1/\upsilon$ was in the range of 81416-143191. There were 37 copper connections for studying the pressure of the bed with 0.006 m diameter on the bed and through the flume centre. The pressure fluctuation was measured by Motorola co pressure transducer. They worked in the limited +10 to -10 Kpa. Spectrometer analyses was set with same signal which were made by Bendat and Piersol (1971). they showed that the frequencies of much pressure fluctuations almost 30 Hz [19].Therefore the frequencies of sampling was chosen 40 Hz.

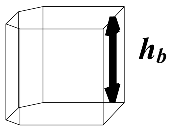


Fig3. 3D shape of Cubed elements

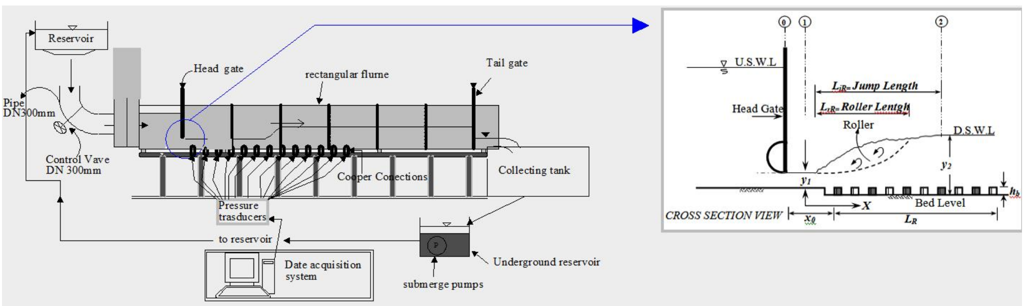
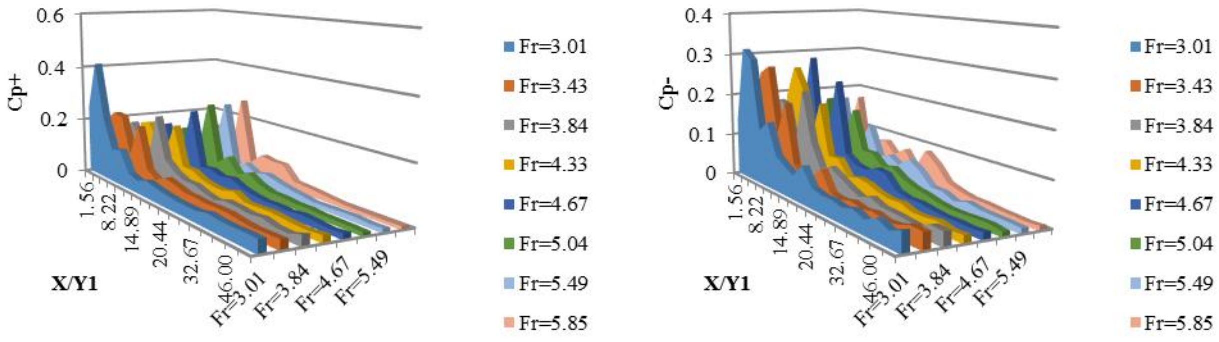


Fig4. Schematic of the experimental setup

RESULTS AND DISCUSSION

In figure 5 the variance of positive and negative fluctuations through of the jump (C_p^+ and C_p^-) has been shown. It can be observe that this variance at the beginning of the jump is hard. But with increasing distance from toe, the intensity will decrease.



A: Positive Fluctuations **B: Negative Fluctuations**

Fig5. Positive and negative fluctuations in abrupt drop B-jump with rough bed

According to figure 5 it can be said that both values of Cp^{+}_{max} and Cp^{-}_{max} decrease and then it stabilized in different amounts. In figure 6,Cp^{-}_{max} and Cp^{+}_{max} has compared with the variance of Fr.

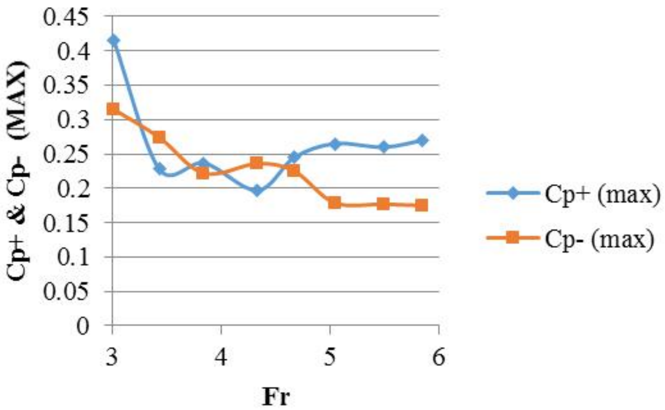


Fig6. Comparing of Cp^{-}_{max} and Cp^{+}_{max} with Fr in B-jump with rough bed

The reason of Cp^{-}_{max} and Cp^{+}_{max} fluctuation in Fr_1<4.5, could be concern the unstable condition of hydraulic jump in Froude number between 2.5 to 4.5. In figure 7 we can observe the decreasing of Cp^{-}_{min} and Cp^{+}_{min} with increasing Froude number. In the analysis of decreasing Cp^{-}_{min} and Cp^{+}_{min} we can say, this decreasing was diversion maximum and minimum from average and this means that the ratio of dynamic pressure is more than the ratio of pressure fluctuations.

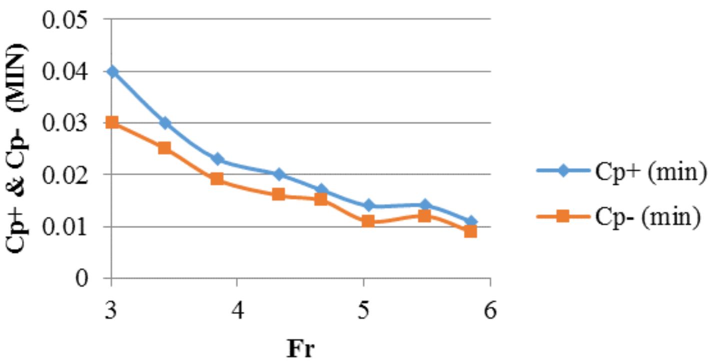


Fig7. Comparing of Cp^{-}_{min} and Cp^{+}_{min} with Fr in B-jump with rough bed

In table 1 amount of C'_p it is specified for different cases of jumps. As we can see in the table, C'_p in negative step with rough bed is always much less than negative step with smooth bed. It was reduce 35% to 84% comparing smooth bed. Also the amount of C'_p in negative step B-jump with smooth bed toward classic jump, at first is increased (negative sign) and then decreased. At the first of the jump in smooth bed, C'_p is more than classic jump. Then with getting off from the toe, it's equal C'_p in classic jump and then become less. The reason of increasing C'_p is decreasing water depth at the first of the jump in negative step toward classic jump. This causes more fluctuation in this area. Also it was observed that the development of vertical vortexes between the roughness rows which is form similar to tornado was happened (see Figure 8). These vortexes can reduce the kinetic energy of flow and reduce the pressure fluctuation or in other words the C'_p value.

As seen, C'_p in negative step rough bed is always less than classic jump. This was happened because of presence the roughness and vertical vortexes between the roughness rows. The above results show that the roughness elements on the bed, can reduce the C'_p value. In other word they can reduce the possibility of basin bed cavitation.

Table1. Comparing of C'p

Jump Type	*Author*	*Fr_1*	*x/y_1*	*C'p*	*% C'p decrease*	*According to*
Classic Jump	*Toso& Bowers*	*5.49*	*8.00*	*0.064*	-	-
	Toso& Bowers	*5.49*	*10.00*	*0.065*	-	-
	Toso& Bowers	*5.49*	*12.00*	*0.064*	-	-
	Toso& Bowers	*5.49*	*15.00*	*0.060*	-	-
	Toso& Bowers	*5.49*	*16.00*	*0.059*	-	-
	Armenioet all	*6*	*8.40*	*0.038*	-	-
	Armenio et all	*6*	*10.00*	*0.054*	-	-
	Armenio et all	*6*	*12.00*	*0.060*	-	-
	Armenio et all	*6*	*15.00*	*0.065*	-	-
	Armenio et all	*6*	*16.00*	*0.067*	-	-
B-jump with Abrupt Drop 1	*Armenio et all*	*6*	*8.00*	*0.128*	*-116.95*	*Armenio et all Classic Jump*
	Armenio et all	*6*	*10.00*	*0.079*	*-107.89*	
	Armenio et all	*6*	*12.00*	*0.065*	*-20.37*	
	Armenio et all	*6*	*15.00*	*0.044*	*26.67*	
	Armenio et all	*6*	*16.00*	*0.041*	*36.92*	
	Armenio et all	*6*	*20.00*	*0.031*	*54.25*	
B-jump Abrupt Drop 1 with Roughness	*This study*	*5.85*	*8.22*	*0.020*	*84.29*	*Armenio et all Abrupt Drop 1*
	This study	*5.85*	*10*	*0.051*	*34.97*	
	This study	*5.85*	*12.00*	*0.038*	*41.95*	
	This study	*5.85*	*15.00*	*0.020*	*54.06*	
	This study	*5.85*	*16.00*	*0.017*	*59.68*	
	This study	*5.85*	*20.00*	*0.014*	*54.30*	

Fig8. The conditions of horizontal and vertical vortexes in flume

CONCLUSIONS

The importance of defining the magnitude and extent of pressure fluctuations in the hydraulic jump has been underscored by the possibility of damage to the containment structures. Severe damage of spillway structures, has been attributed to these forces. Statistical parameters of turbulence in the hydraulic jump have been studied by several investigators, but yet data with regard to the maximum pressure fluctuations are lacking. In this paper the pressure fluctuations beneath a hydraulic jump that develops over a negative step with rough bed have been investigated.

The following general conclusions were made:

1- The effect of roughness on hydraulic jump with negative step is obvious and these influences are decreasing energy in jump and hydrodynamic forces on bed.
2- Increasing of Froude number makes the cavitation more.
3- The amount of $C_p^-{}_{max}$ and $C_p^+{}_{max}$ in negative step with rough bed, decreasing with increasing Froude number for Fr<4.5 and then reaches the specific point.
4- The amount of $C_p^-{}_{min}$ and $C_p^+{}_{min}$ in negative step with rough bed, decreasing with increasing Froude number for every Froude numbers.
5- C_p^- and C_p^+ in negative step with rough bed will be reduced more than 90% comparing smooth bed.
6- C'_p in negative step with rough bed is less than negative step with smooth bed. This phenomena is because of vertical vortex in behind of roughness.
7- C'_p in negative step with rough bed is less than classic jump.

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