Effects of non-continued artificial roughness in pressure fluctuations at the bottom of negative step

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Abstract:

Experimental evidence of the statistical structures of turbulence pressure fluctuations at the bottom of hydraulic jumps over a negative step with rough beds is brought out in this paper. Hydraulic jump stilling basins are used as an energy dissipater structures downstream of gates spillways and weirs. In the present study the effect of roughened bed on flow characteristics of hydraulic jump at abrupt drop, has been experimentally investigated. Total of 75 tests conducted in a flume of 80 cm in width and 15 meter long. Experimental were performed for wide range of Froude numbers ranging from 3.03 to 11.68. The experimental results herein reported may be helpful in the design of a stilling basin with a negative step and rough beds, with particular reference to the thickness of the concrete slabs required to ensure the stability of the slabs. The results show that the roughened bed can decrease the pressure fluctuations which can reduce the required slab thickness compare to the classic jump.

Key words: Hydraulic jump, negative step, artificial Roughness, Pressure Fluctuations

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INTRODUCTION

The use of a vertical downwards step to control and stabilize the position of hydraulic jump is well known. The effectiveness of such drop on the stabilization of the hydraulic jump for a wide range of the downstream depth values has been widely studied by Moore and Morgan (1959). Figure 1 shows several types of jump at an abrupt drop in a stilling basin for a given supercritical upstream flow with mean velocity v1 and depth y_1. If the tailwater depth (y_2) is relatively large, the hydraulic jump is located in the upstream channel; this type of jump is called A-Jump (Aj). If the depth y2 is reduced, the Aj is replaced by a wave that occurs at the drop. This type of jump is called Wave-Jump (Wj). By further reduction of y_2 a B-Jump (Bj) will occur with the toe located near the drop. The use of a jump for the dissipation of energy in a spillway basin especially while operating under flood conditions may produce some unpredicted effects such as slab failure (Di Santo et al., 1995). Many investigators have shown that turbulent pressure fluctuations beneath hydraulic jumps are responsible for the loss of stability of the slabs(Sanchez and Viscaino, 1973; Bowers and Tsai, 1969). The slab failure is due to the severe pulsating pressures in the hydraulic jump region, which may damage the joint seal of the slabs, the instantaneous difference between the total pressure acting on the upper and lower surfaces of the slab can reach high values, causing the total uplift force to exceed the weight of the slab, and it may play a relevant role in the magnitude of the overall lifting force. Because of this researchers have been tried to established slab design criteria to include the pressure fluctuation.

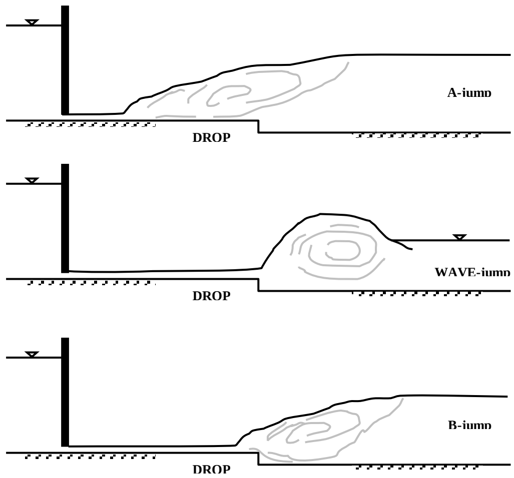

Fig. 1. Hydraulic jumps over a negative step

Fiorotto and Rinaldo (1992a) proposed a design criterion for the maximum thickness of the slabs based on the magnitude of the uplift force induced by severe fluctuations associated with energy dissipation in the hydraulic jump region:

$$s > \Omega\left(\frac{l_x}{y_1}, \frac{l_x}{I_x}, \frac{l_y}{I_y}\right)(C_p^+ + C_p^-)\frac{v_1^2}{2g}\frac{\gamma}{\gamma_c - \gamma} \qquad (1)$$

In Eq. 1 s is the thickness of the slab, Ω is the dimensionless reduction factor; lx, ly are the longitudinal and transversal length of a single slab, or the span between the joints; Ix, Iy represent the longitudinal and transversal integral scale of pressure fluctuations whereas γ and γ_c are the specific weight of water and concrete, respectively. The coefficients Cp are derived from the following relations:

$$\frac{\Delta p_{\max}^+}{\gamma} = C_p^+ \frac{v_1^2}{2g} \quad , \quad \frac{\Delta p_{\max}^-}{\gamma} = C_p^- \frac{v_1^2}{2g} \qquad (2)$$

Where $\Delta p_{\max}^+$ and $\Delta p_{\max}^-$ are respectively the maxima of the positive and negative pressure fluctuations, measured with reference to the mean value. The use of Eq. 1 as an engineering tool requires the evaluation of the maximum negative and positive fluctuating pressures as well as of the reduction factor Ω. It plays a relevant role in the definition of the maximum uplift force as a function of l/I. As previously pointed out, the uplift force is due to the instantaneous pressure differentials that occur between the upper and the under surface of the slab. The pressure field beneath the slab depends on the fluctuating pressures forced through the joints at the tips of slab. If l/I vanishes the pressure field over and under the slab is fully correlated, hence the uplift force as well as Ω tend to zero. The increase of l/I reduces the correlation of pressure field over the slab with that along the joints, thus instantaneous maximum pressures can occur along the joints while the upper part of the slab is experiencing an instantaneous minimum of the pressure fluctuation: this circumstance makes the Ω coefficient, and consequently the uplift force, to reach a maximum value. In a recent experimental investigation, Bellin and Fiorotto (1995) have found out Ω to be in the range between 0.05 and 0.25 for 0.5 < lx/Iy, ly/Iy < 2.0 depending on the slab's shape, though it has been also showed that Ω can reach even larger values. Indeed, Fiorotto and Rinaldo (1992a) theoretically found out an estimated upper bound of Ω as large as 0.75, pointing out the importance of the experimental evaluation of the correlation function of the pressure fluctuations in the design of the lining slabs in stilling basins via Eq. 1. During the past decades many studies have been reported the use of roughened bed stilling basin. Rajaratnam(1968), Ead and Rajaratnam(2002), Izadjoo and Shafai Bejestan(2007), Shafai Bejestan and Neisi(2009). The main conclusions of those studies are that the roughness can developed a shear stress which reduces the hydraulic jump length by about 50 percent and the tailwater depth is about 20 percent. Since for abrupt jump of roughened bed basin has not been studied in the past this study was conducted for the purpose of measuring pressure fluctuation beneath a B-jump at an abrupt bed in order to investigate the effect of roughness on the thickness of the slabs by means of Eq.1.

MATERIALS and METHODS

Tests were carried out at the hydraulic laboratory of the Shahid Chamran University of Ahwaz. 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 plexy glass. Water was pumped from a storage tank to the head tank of the flume by a centrifugal pump.

A cubed element made of hard plastic was installed on the flume bed (Fig.2) in such a way that the crests of the cubes were at the same level as the upstream bed. ($s=\Delta Z_0$). 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 heights of step were 3.5 and 4.5 .A gate (tailgate) at the exit end of the flume provided the control on the position of the jump. In all experiments, the gate (tailgate) was adjusted so that the jumps were formed B-jump (That this later is shown Bj®) (Fig. 3). 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 11.68. The Reynolds number $Re_1=v_1y_1/\upsilon$ was in the range of 81416-143191.

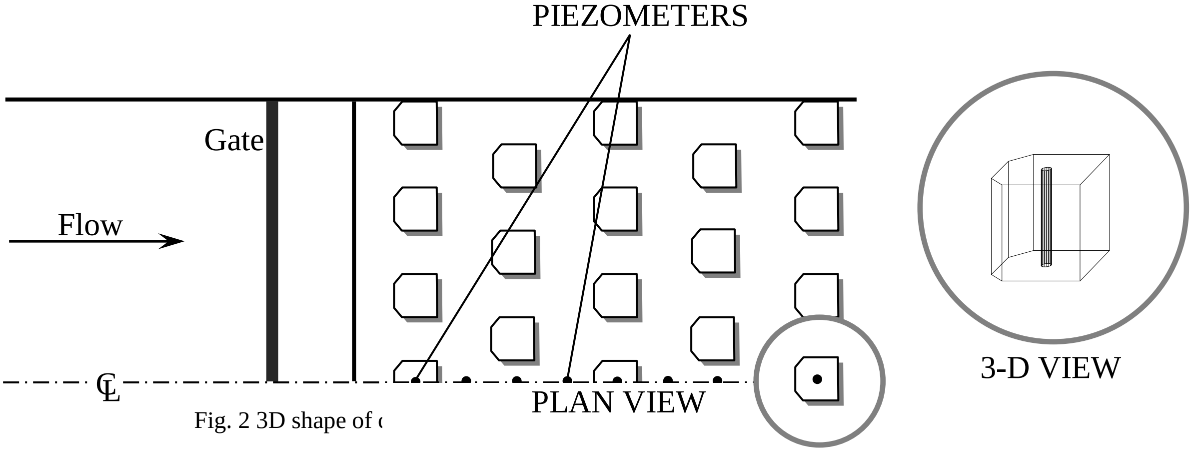

Fig. 2 3D shape of

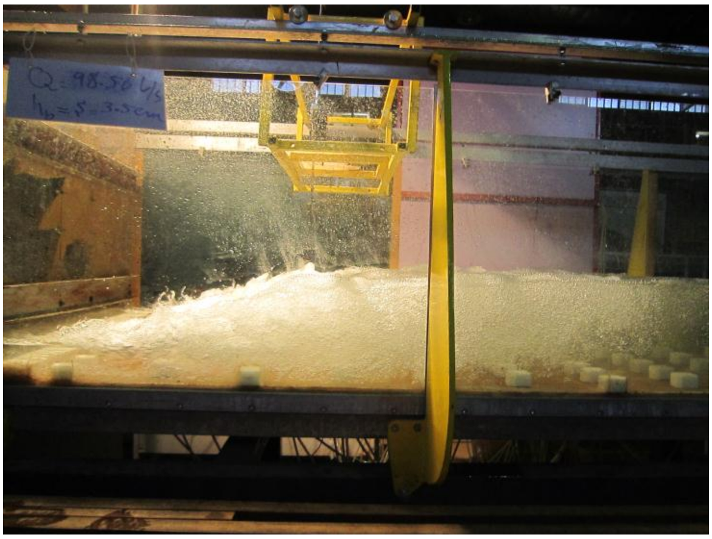

Fig. 3 B-jump at an abrupt drop with rough beds

Under the slab, in contact with the bed of the flume, pressure taps were inserted. The pressure transducers connected to the taps under the slabs with a range of ± 10kpa. In order to measure the pressure fluctuations the computer was linked to the transducer via a 12-channel digital board DM5010S (manufactured by Motorola). The pressure taps were connected to the transducer by Flexible tube. The maximum length of the connection tube was 1m. The pressure fluctuations were measured in 75 points.

RESULTS

An important factor for slab design concerns the range of pressure fluctuations, here defined by the pressure coefficient C_p^+, C_p^-. Since the hydrodynamic forces without positive and negative pressure coefficients cannot be considered, therefore, these coefficients are examined in this section. Fig.5 was shown the amounts of C_p^+ and C_p^- for different Froude numbers. In Fig. 5 variation of maximum, average and minimum pressure fluctuations along the hydraulic jump for two experiments is shown. It can be seen that fluctuations are high at the beginning of jump. As further downstream by increasing water depth these values are decreased get close to each other. This figure shows, at the pizeometer 4, maximum pressure will suddenly drop, Because the submerged jet, at this point osculated at the bottom of the flume

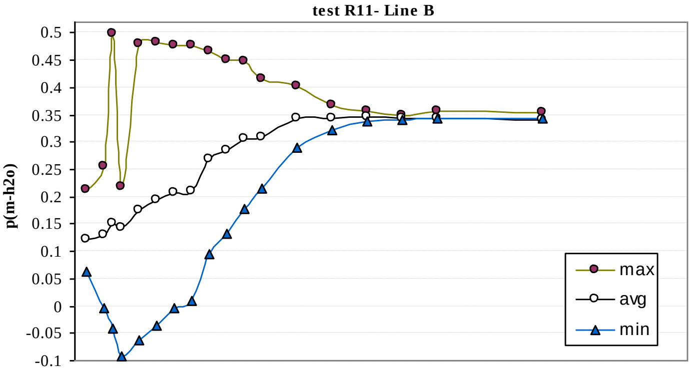

Fig. 4 maximum, minimum and average of pressure fluctuations along the hydraulic jump

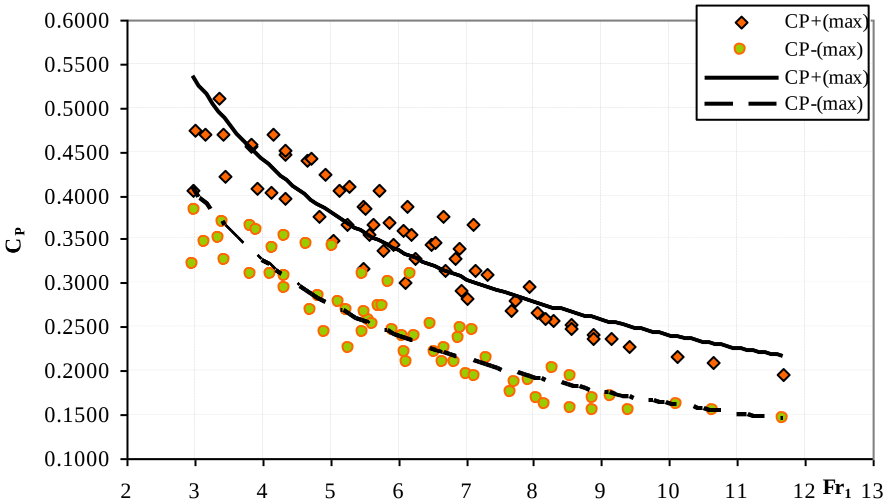

Fig. 5 pressure coefficient (C_P) as a function of Fr_1

This high value can be due to unstable conditions in the hydraulic jump Froude numbers between 2.5 and 4.5 attributed. It can be noted that the minimum amount of positive and negative pressure coefficient decreases with increasing Froude number. In analyzing the decrease positive and negative coefficients with increasing Froude number, can be said that this reduction represents a decrease of the average value is the maximum and minimum deviation. This means that increasing dynamic pressures are greater than increasing pressure fluctuations. These two charts are carefully specified that the maximum and minimum values in both positive and negative pressure coefficients, the values of C_p^+ are more than C_p^-. Maximum values of positive and negative pressure coefficients initially occurs in the same locations and at $Fr_1<4.83$. When $Fr_1>4.83$, the value of C_p^+(max) and C_p^-(max) are fixed in x/y_1 = 13.43 and x/y_1 = 4.86 respectively. The minimum values of positive and negative pressure coefficients of the variable to have a Froude number, but within the range $40 < x/y_1 < 80$ occur. The sampling time used to calculate the correlation coefficient was 180 s. In Fig. 6 normal distribution in the location was compared between *Cj* and *Bj*®. The maximum error in the estimate of the normalized correlation coefficient obtained repeating the same experiment in various different instants was less than 4%. Our results indicate that $Ix = (0.35-1.2)y_1$ in the actual experimental condition $(3.03 \le Fr_1 \le 11.63)$. Also, $I_y \approx 2.65y_1$. A stability criterion can be inferred by the equilibrium balance for the vertical forces:

$$s > \frac{F' + \overline{F}}{\gamma_c A} \tag{3}$$

Where s= the equivalent thickness of slabs(the equivalent thickness means that if the structure is anchored to underlying rock, the failure strength of the anchors must be transformed into equivalent weight); F' = the fluctuating uplift; and $\overline{F}$ = the uplift due to difference between the average pressure $\approx \gamma_s A$. substitution $F' \cong \frac{A\gamma v_1^2}{2g}(C_p^+ + C_p^-)\frac{\beta}{2}$ in (3) yields:

$$\frac{s}{\frac{v_1^2}{2g}} > \Omega \frac{\gamma}{\gamma_c - \gamma}(C_p^+ + C_p^-) \qquad (4)$$

Where $\Omega =$ the dimensionless reduction factor, equal to the overall reduction factor, a function of the shape and dimensions of the slabs and of the instantaneous spatial correlation structure of turbulent pressures, and $\beta/2$ is replaced by the dimensionless reduction factor Ω. Fig. 6 shows measurements value of the Ω along of Bj® for different value of Froude number.

This paper presents the results of an experimental investigation undertaken to evaluate the statistical parameters of the pressure fluctuations beneath a Bj® in order to evaluate the thickness s of the slabs by means of Eq. 1. Pressure fluctuations beneath a hydraulic jump that develops over a negative step with roughened beds have been investigated.

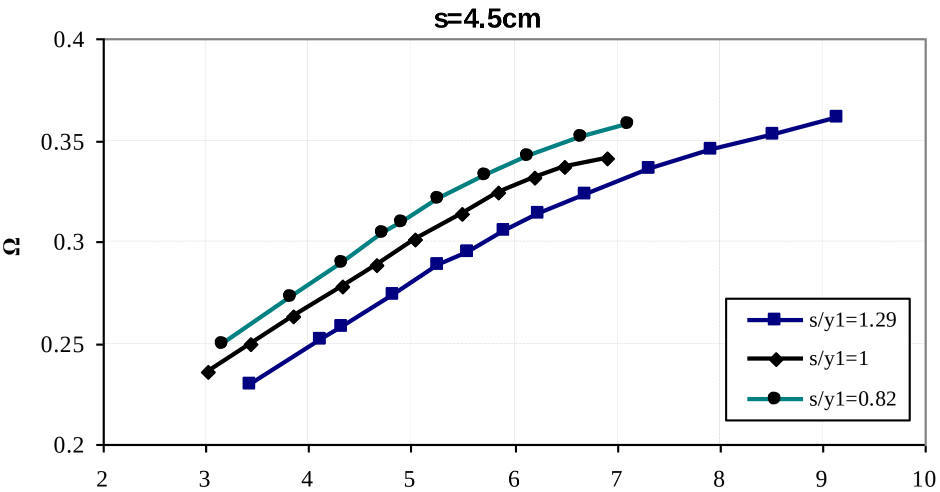

Fig 6. *Values of* Ω *for s/y₁ and different values of Fr₁*

Conclusions

The study was carried out experimentally, using two different drops, an abrupt drop with rough beds, and varying the inflow and outflow conditions of the flume in order to obtain a Bj® .The analysis has shown that:

1- In the Bj® stilling basins thickness equal to Cj, but *Bj* stilling basins require thickness as large as three times those computed for *Cj*.

2- It is clearly shown that in Bj® the positive fluctuating pressures are relatively more than the negative ones.

3- The maximum value of the compound coefficient $C_p^+ + C_p^-$ can be derived, and it clearly appears that for Bj® it is smaller than Bj.

4- In abrupt drop with roughened beds, the amount of C_p^+ is always higher than C_p^-.

5- The probability density function of the pressure fluctuations can be assumed reasonably Gaussian, thus this assumption can be used for the overall estimation of Ω.

6- Assuming $\gamma(\gamma_s - \gamma) = 0.65$ minimum and maximum value of Ω is in the range between 0.19 to 0.38 respectively for $3.03 < Fr_1 < 11.68$.

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