The Effective Pressure on the Chutes of Stilling Basins

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Abstract

Energy dissipaters are one of the most important parts of high dams. Of these structures, stilling basins are used extensively to reduce the destructive energy of water, passing down the spillway of high dams. The formation of hydraulic jump within the stilling basins is one of the main important tasks in the design of such structures. Therefore, it is recommended to keep the tail water slightly higher than the secondary depth to ensure the formation of jump within the basin. But, in normal operation, this suggestion may cause the jump to form on the upstream chute. Formation of hydraulic jump on the chute may trigger considerable uplift force beneath the slabs of the chute, and thus, causes structural damage. Therefore, a set of experiments was performed in a long flume at Water Research Center in Iran to determine the maximum and minimum pressure differences along the chute. The results provide valuable information, which can be used in the structural design of such structures.

Introduction

Hydraulic jump is a rapidly varied transition from supercritical to subcritical flow through which energy is dissipated due to generation of large-scale turbulence. The process of energy dissipation in hydraulic jump is associated with hydrodynamic pressures acting on the floor and sidewalls of stilling basins. Damages due to pressure fluctuations under hydraulic jump have occurred in several stilling basins around the world. Lifting up the whole floor slabs, fatigues of materials, and cavitation are the main damages cause by pressure fluctuations (Kavianpour, 2000).

Major damages due to pressure fluctuations have been reported in several stilling basins such as, Karnafuli dam in Bangladesh and Malpaso in Mexico. Studies showed that the magnitude and extend of these fluctuating pressures are strongly depend on the geometry of stilling basin and incoming flow conditions. However, there is still a lack of information on the effect of these pressure fluctuations and their quantitative values. The study reported herein, contains useful information about the magnitude of effective pressure fluctuations beneath hydraulic jump forms on the upstream chute of stilling basins for Froude numbers of 6, 8 and 10.

Literature Review

In 1971 Schiebe and Bowers studied the statistical characteristics of pressure fluctuations under hydraulic jumps. Leuthesser and Kartha (1972) showed the effect of inflow development on the magnitude of fluctuations, using the measurements of velocity fluctuations provided by hot film anemometer. Abdul Khader and Elango (1974) studied the statistical characteristics of fluctuating pressure under hydraulic jumps with Froude numbers of 4.7, 5.9 and 6.6.

Early studies showed that spillway of high dams may subject to major damages, although the flow is less than the maximum flood design. Recent studies showed that turbulent pressure

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fluctuations in hydraulic jump are responsible for such damages. For example, Bowers and Toso (1987) presented their results of the model studies of spillway damage for Karnafuli dam. The dam was constructed in June 1961 in Bangladesh, having 41.5m height. It consists of a 227m-width spillway to allow maximum floods of $18000m^3$/sec. In August of the same year, due to a flood of $3480m^3$/sec (20% of the maximum flood), slabs of the chute and stilling basin were faced serious damages. The damage covered an area of 23m long and 180m width. Bowers and Toso recommended that if hydraulic jump forms far upstream on the chute, the outlets of drain system and the floor slabs of the chute may subject to high pressure fluctuations. The results of their model studies with the discharge of $3480m^3$/sec showed a difference pressure of 4.9m (=$47900N/m^2$ uplift pressure) between the outlets of the drain system and the selected points on the chute. The weight of the concrete slabs in the basin was $10700N/m^2$. Therefore, they suggested that the slabs faced a net uplift pressure of around 5 times of their weights. Finally, they concluded that pressure fluctuations were responsible for the damage occurred to the stilling basin and the chute of Karnafuli dam.

In 1970 major damages happened to the slabs of stilling basin of Malpaso dam in Mexico under 20% of maximum designed flood. The slabs were 12m×12m, having 2m thickness and 720ton weight. Although the slabs were fixed to the ground stones, but were detached from their position, which caused serious damages to the structure. Studies showed that pressure fluctuations were the main source of damages. In 1982, Lopardo et al. also showed that severe pressure fluctuations may increase the cavitation risk. In 1982, Akbari et al. investigated the turbulence pressure characteristics of free and forced hydraulic jumps. In 2000, Pirooz and Kavianpour studied the effect of inflow condition on pressure fluctuations beneath hydraulic jump with Froude numbers of 6, 8, and 10.

In this study systematic measurements were made along a chute and at the same time, at the end of the chute, where usually the outlet of drain system is placed. Hydraulic jump were formed on the chute with different incident Froude numbers to find out the effective pressure caused by hydraulic jump on the slabs, due to pressure transfer by drain system underneath the chute and that of happens on the chute. The results will provide information on the magnitudes of effective pressure fluctuations caused by hydraulic jump, which forms on the upstream chutes.

Experimental Investigation

As the pressure fluctuations are random in nature, statistical quantities such as average (P_{mean}), standard deviation (RMS), and their maximum (P_{max}) and minimum (P_{min}) magnitudes are used in this study. However, the designer of hydraulic structure also uses pressure fluctuations with different probability occurrence to evaluate the cavitation risks (Lopardo, Hening, 1985). The results are non-dimensioned with respect to the incident flow velocity, in the forms of:

$$C'p^{+} = \frac{p_{\max} - p_{mean}}{U^2/2g}$$

$$C'p^{-} = \frac{p_{\min} - p_{mean}}{U^2/2g}$$

$$C'p = \frac{RMS}{U^2/2g}$$

In this study the effective pressure fluctuations, which is the maximum difference between, the pressure at the position of outlet drain (at the end of the chute) and the pressure along the chute are presented in the following form:

$$Max(C'p) = C'p^{+}_{outlet} - C'p^{-}_{chute}$$

Experiments were performed in a glass walled rectangular flume having 0.75m wide, 0.85m deep and 12m long at Water Research Center of the Ministry of Energy, Tehran, Iran. The horizontal bed was made of 3mm steel plate, reinforced with lateral and longitudinal steel profiles, to prevent possible vibrations and resonance to occur. Water was supplied to the flume by a pump, having maximum discharge of 200 lit/sec. The sloping section was made of wooden ramp, with a slope of 25^0. The ramp was sealed by fine rubber material. Great care was also taken to prevent any disturbances from incident flow entering the jump. A sluice gate was placed at the inlet of ramp to control the depth and velocity of incoming flow, while the location of jumps were controlled by a tail gate placed at the end of the flume.

The depth of entering flow was measured at the toe of jump by means of point gage with the accuracy of ±0.1cm. Having changed the depth of flow behind the sluice gate, the incident flow velocity and therefore, the Froude number could be fixed. In this study, the depth of entering flow was 0.009cm, and the Froude numbers were 6, 8 and 10. The slope of the stilling basin was also change at S=0.005, -0.015 and –0.025. These stilling basins have the advantages of reduction in the length of the jump and the magnitudes of pressure fluctuations (Kavianpour, Mohammady, 2001). Figure 1 shows a schematic view of the experimental set-up. Pressures fluctuations were measured using pressure transducers type HBM P11 (1bar) with effective diameters of 1.5cm. Pressure taps, having 2mm diameter, were fixed at every 3cm along the centerline of the ramp. The distance between the taps was so selected to collect all possible pressure peaks. Connection tubes (PVC) with internal diameter of 8mm and maximum length of 1.5m were used to connect the pressure taps to the pressure transducers (Lopardo, Hening, 1985). Every time, measurements of three of the taps on the chute (of 21 taps) plus our reference tap at the end of the chute were made, simultaneously.

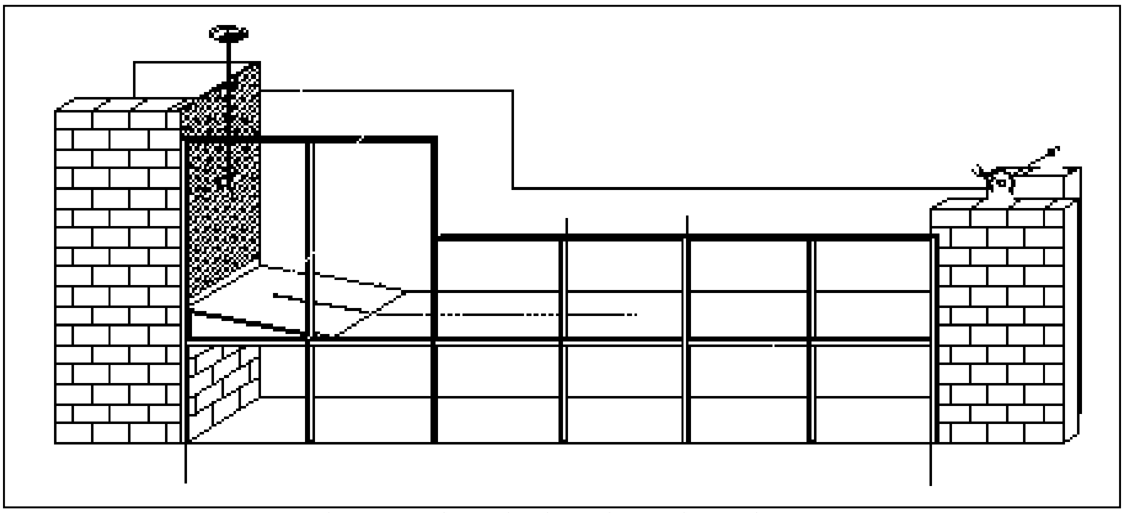

Figure 1: Schematic view of Experimental Setup.

It has been established that the dominant frequencies of pressure fluctuations in the hydraulic jump (model) are bellow 25Hz (Toso, Bowers, 1988; Akbari et. al., 1982). Therefore, a sampling rate of 100Hz was used to ensure the collection of important peaks. A 4-channel data acquisition system was operated to collect the pressures with a sampling period of 60Sec. A software was also developed to compute the statistical parameters such as, maximum, minimum, average, and standard deviation (or RMS) of pressure fluctuations.

Experimental Results

In this study a wide range of experiments were made, but regarding the paper size limitation, only some typical results are presented. However, the data and results are available for those who may be interested (Mohammady 2001). Figure 2 shows the variation of maximum pressure difference for three Froude numbers of 6, 8 and 10. The slope of the stilling basin is –0.005. In this figure, horizontal axis represents the distance from the beginning of the jump, non-dimensioned with respect the depth of incident flow and vertical axis shows the maximum pressure difference. It should be mentioned that, on the sloping chute, the term $\Delta Z + U^2/2g$ can only be used to describe the total energy entering the jump. Therefore, if ΔZ is the height between the toe of the jump on the chute and the pressure taps, the resulting relationships will be derived in the forms of:

$$C'p^{+} = \frac{p_{\max} - p_{mean}}{\Delta Z + U^2/2g}$$

$$C'p^{-} = \frac{p_{\min} - p_{mean}}{\Delta Z + U^2/2g}$$

$$C'p = \frac{RMS}{\Delta Z + U^2/2g}$$

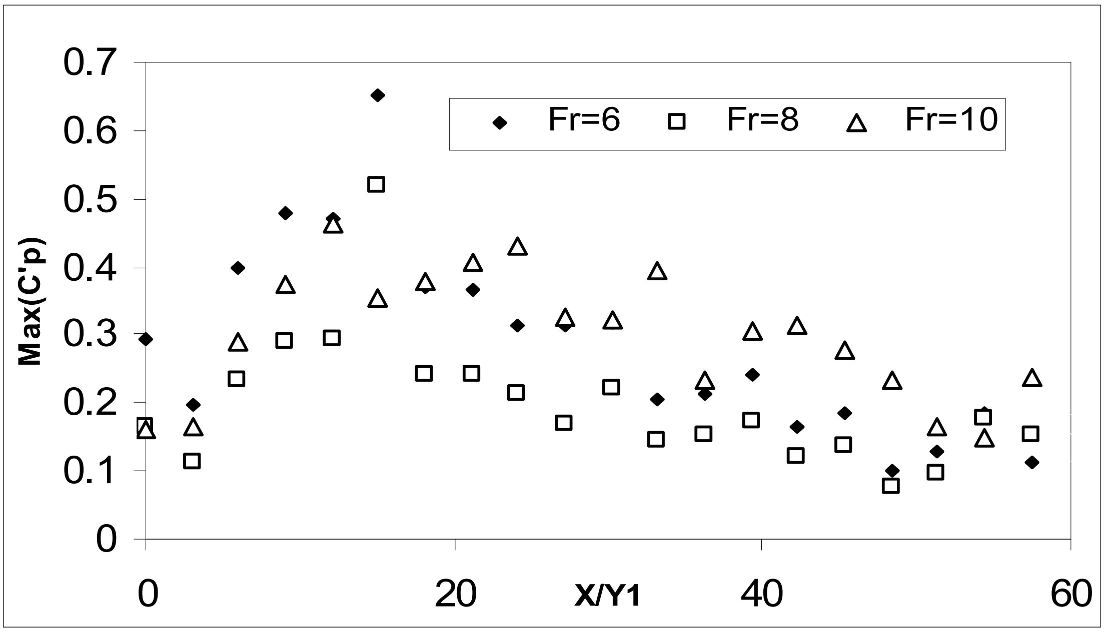

Figure 2: Variations of effective pressure along the chute (S=-0.005).

It is observed from Figure 2 that the pressure difference reduces with increasing froude number. The figure shows that maximum difference pressure varied from 0.5 to 0.68, occurring at $10 < x/y_1 < 20$. Downstream of $x/y_1 = 20$, no significant changes are observed.

Figures 3 and 4 show the results measurements for stilling basin with slopes of –0.015 and –0.025. Similar trend, compared to the figure 3, can be observed from the figures. Maximum difference pressure ranges from 0.6 to 0.7 in Figure 3 and 0.5 to 0.88 in Figure 4, occurring both at $10 < x/y_1 < 20$ as well.

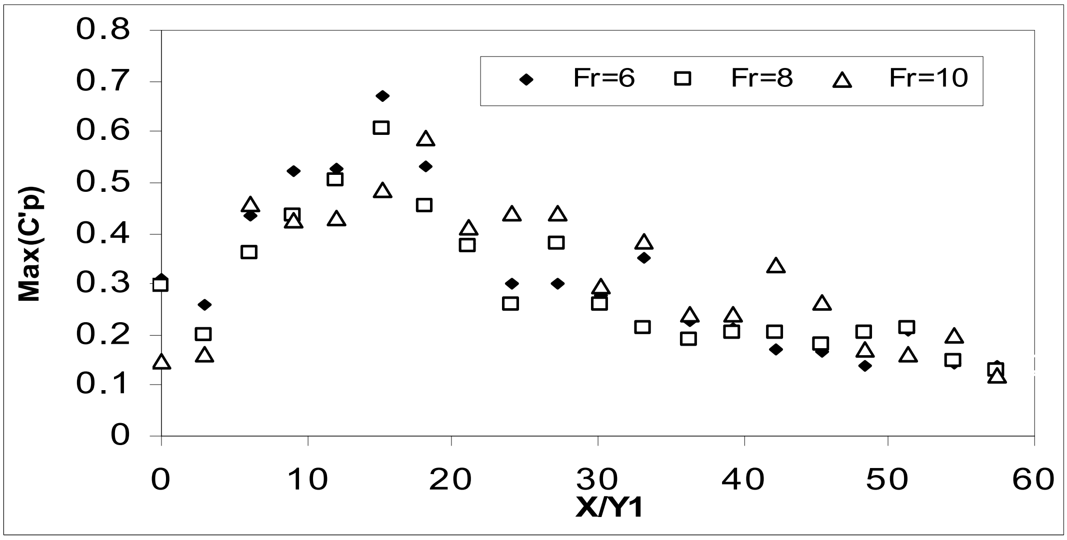

Figure 3: Variations of effective pressure along the chute (S=-0.015).

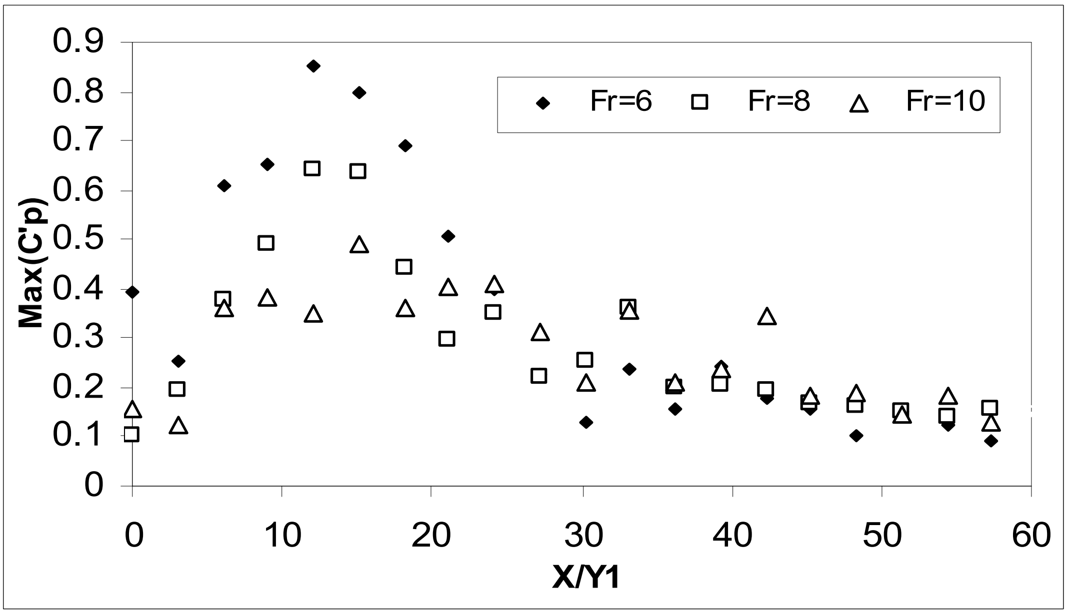

Figure 4: Variations of effective pressure along the chute (S=-0.025).

Figures 5 and 6 show the comparison of all results. Figure 5 presents the maximum values of pressure difference and Figure 6 shows the minimum values. It is observed from the figures that the maximum pressure difference increases with increasing the negative slope of the basin, reaching a value of 0.88 at some distance x/y1=12. The minimum values of pressure difference also increases as the negative slope of basin increases, reaching a value of 0.78 at some distance x/y1=10. Figure 7 also covers the results of maximum and minimum pressure differences provided from this study. These results can be suggested for the structural design of the slabs of the chute. The figure shows that placing the outlet drain at the end of the chute will introduce a dynamic pressure, herein called effective pressure difference, which acts in two ways of uplift or adding weight to the slabs of the upstream chute of stilling basins.

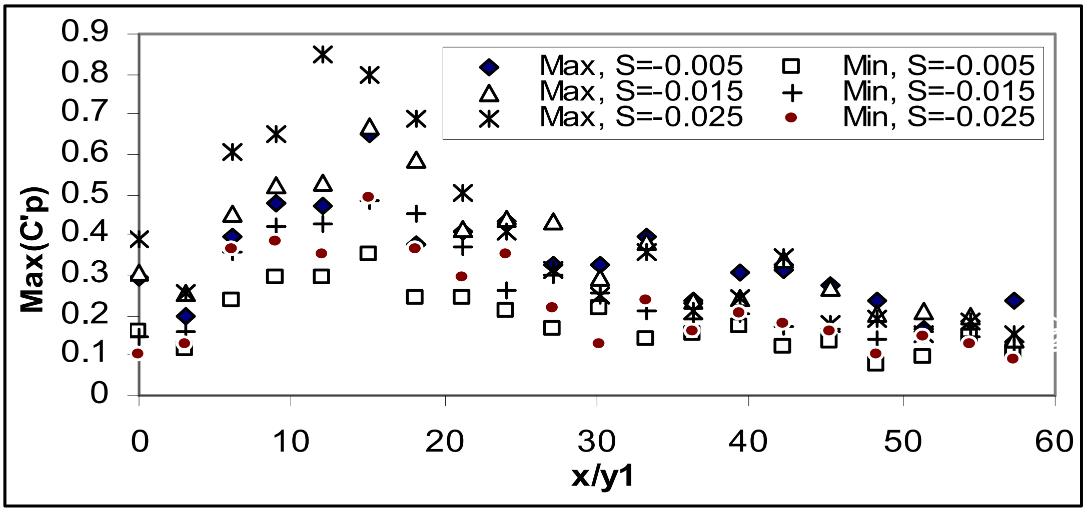

Figure 5: Comparison the maximum pressure differences along the chute.

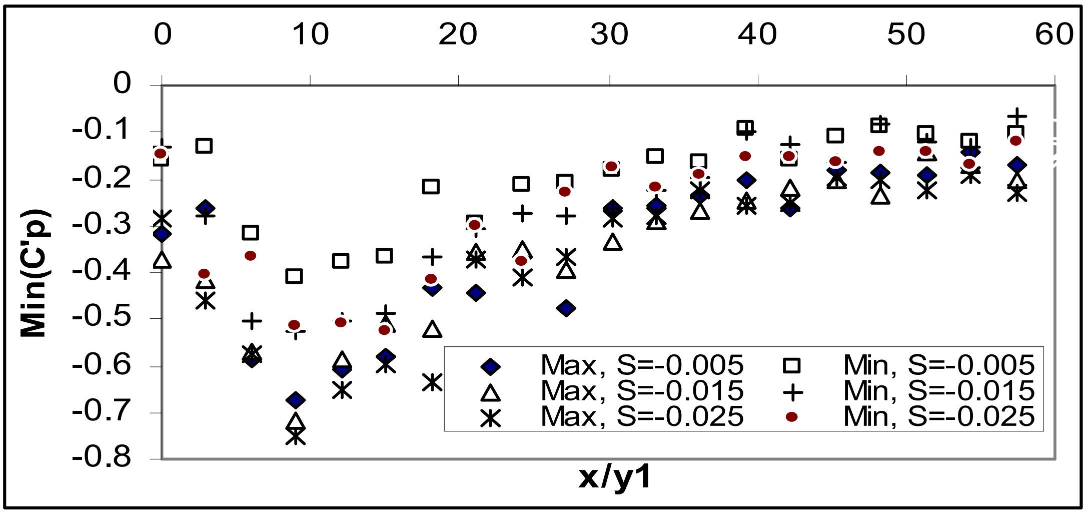

Figure 6: Comparison the minimum pressure differences along the chute.

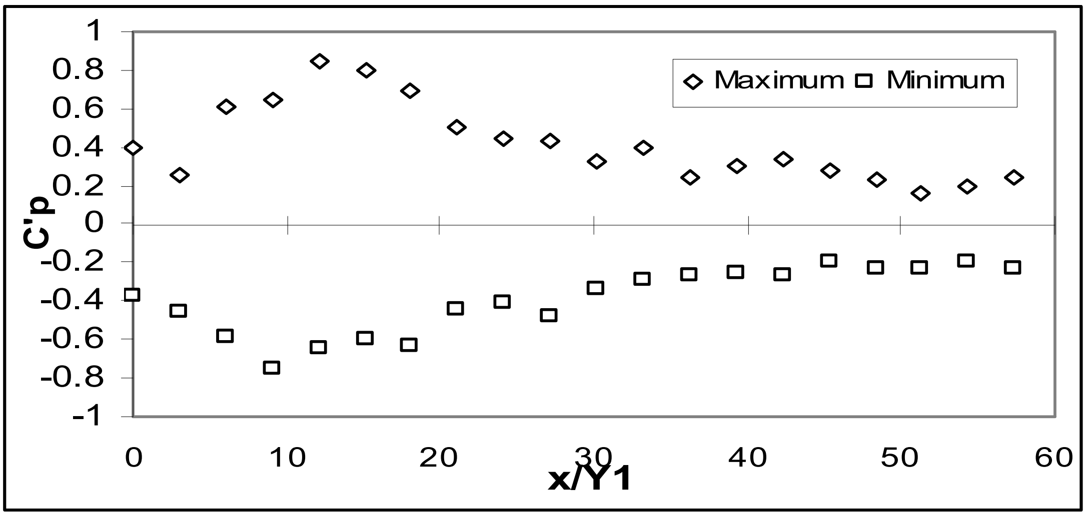

Figure 7:The over all results of maximum and minimum pressures on the chute.

Conclusion Remarks

From the results it is concluded that:

- If the outlets of drain systems are placed at the chute blocks, care should be taken to the additional forces initiated by pressure fluctuations.
- The resulting dynamic forces have nearly similar magnitudes, but acting in two ways of uplift and adding weight (refer to Figure 7).
- The effective pressure difference reduces with increasing the froude number.
- The slope of stilling basin affects the pressure difference.

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Summary
If hydraulic jump forms on a chute, a positive pulse at drain outlets may coincide with negative pulses on the chute, causing uplift forces, which may damage the slabs of the chute. Therefore, a set of experiments was performed in a flume for three Froude numbers. Pressure fluctuations were measured on the chute and at the end of the chute, where drain outlets are fixed, to find out the effective pressures along the jump.

Keywords: Stilling Basin, Hydraulic Jump, Pressure Fluctuations, hydrodynamic Pressure, Turbulence, Cavitation