Middle-East Journal of Scientific Research 8 (1): 282-287, 2011
ISSN 1990-9233

Dynamic Pressure Distribution of Vertical Jets in Bottom and Sidewalls of Plunge Pools Due to Pool Dimensions

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Abstract: The falling jet downstream of hydraulic structures has high energy and can be a hazard to the environment. If this energy is not properly dissipated, it will cause scour and therefore will endangers dam stability and leads to structural safety problems. The plunge pool is one of the energy dissipater structures for this kind of flow, which the jet enters into the pool with a turbulent and fluctuating flow. In this way the excess energy of the flow is dissipated together with significant dynamic pressure exerted on the floor and pool walls. Since, the evaluation of hydrodynamic pressure fluctuations is very important factor for scour depth and slab design, hence, dynamic behavior of the jet in the pool becomes essential. Thus, in this research, pressure transducers are used to record the fluctuating pressure using experimental model of vertical jets in plunge pool. The variables are; discharge, nozzle diameter, water depth in pool, pool width and sidewall slope. The results show that decreasing bottom width from 12D to 6D (D is the jet diameter)and increasing the sidewall slope has no significant effect on dynamic pressure on the pool floor but increases the maximum pressure and decreases the minimum and mean dynamic pressure on the sidewall. The maximum amount of mean dynamic pressure C_P for Y/Dj=2.04 has obtained as 0.92. The maximum amount of dynamic pressure fluctuations RMS is 0.21 for Y/Dj=2.24 and maximum positive pressure is 0.5 for Y/Dj=4.10, while the minimum negative pressure is 0.8 for Y/Dj=2.25. (Y is the water depth in pool and Dj is the impact jet diameter).

Key words: Plunge pool · Falling jet · Hydrodynamic pressure · Energy dissipation

INTRODUCTION

The falling jet downstream of dams and its movement in the river could cause scour in the foundation of structure and in river basin. This process could endanger dam stability and lead to structural safety problems. Plunge pools are one of the energy dissipater structures in the downstream dams which the energy of the falling jet is dissipated due to impact to the water surface, entrance in the water and diffusion inside the water. Plunge pool design is generally based on the determination of the scour depth with the parameters such as discharge, downstream depth, water split level in reservoir and bed material size. In some specific condition, the design of plunge pools using the scour depth is not suitable due to economical and safety reasons. In this case artificial pools are utilized and design is performed by pressure distribution determination in floor and pool walls and their fluctuation range with discharge, jet velocity, falling head, Froude number, water depth in pool and pool dimension. In energy dissipater structures, some characteristics of turbulent flow such as no homogeneous, anisotropic and 3D variations and absence of a deterministic solution for fluctuating pressure determination in these structures made the investigation in this field difficult. So dynamic records achieve vital important. Previous works in this field have been studied by Cola in 1965 [1], Bearman in 1972 [2], Novak in 1984 [3], Castillo in 1991 [4], Armengou in 1991 [5], Ballio, Franzetti and Tanda in 1994 [6], Ervine *et al*. in1997 [7], Liu *et al*. in 1998 [8], Borghei and Etminani in 2001 [9], xu *et al*. in 2002 [10] and Bollaert and Schleiss in 2003 [11,12]. However, not much study exists on the effect of plunge pool width and sidewall slope on the dynamic pressure distribution at the bottom and sidewalls of plunge pool. This paper presents experimental results due to this phenomenon. Tests have been carried out due to vertical circular jets in a plunge pool with various, discharge, nozzle diameter, water depth, pool width andwall slope.

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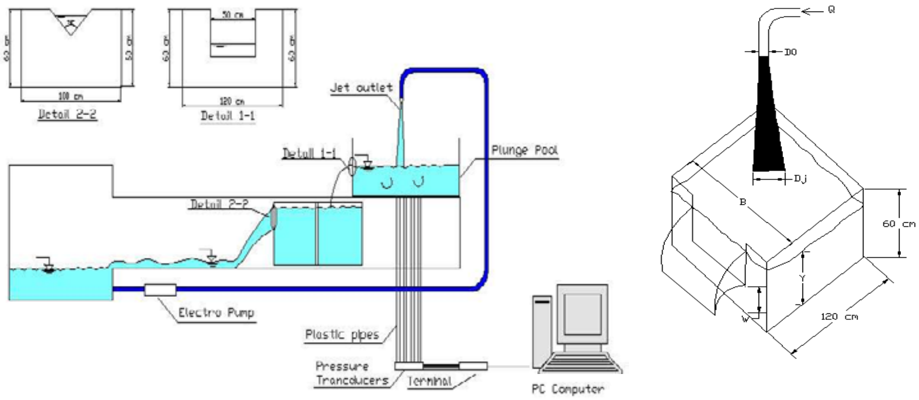

Fig. 1: Perspective and side view of the experimental facility

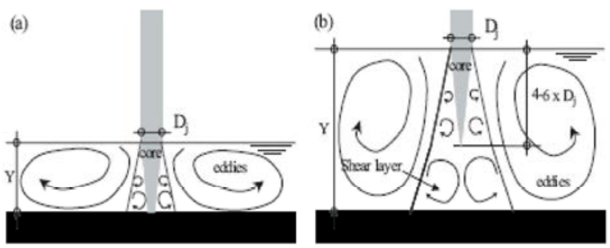

Fig. 2: *Plunging jets: (a) jet core impact (for Y/Dj < 4–6); (b) developed jet impact (for Y/Dj > 4-6).*

Experimental Facility and Jet Characteristics: The perspective and side view of the experimental facility is shown in (Fig. 1). *P*lunge pool model was made of Plexiglas with dimensions of 120-cm in the direction of outflow (longitudinal direction), variable width (B) of 60 to 120-cm (transverse direction) and height with 60-cm and outlet control weir height (w) of 15 and 25-cm. Three different falling jet diameters (D) 5.5, 7 and 10-cm have been used at different discharge (Q) from 5 to 30 lit/s, pool depth (y, which was dependent to Q and w) and two different wall slop 1:2 and 1:3. Overall 126 tests were carried out to find the pressure fluctuations on the plunge pool bottom and wall. The pressures were measured using pressure transducers with 10 kHz sampling rate, which were connected to the bottom and walls. In the center of bottom, for an area of 20 by 20-cm, the pressures were measured at a distance of 5-cm and beyond that at intervals of 10-cm to each side of the center. Also, on the wall, the measured pressures were at a distance of 10 cm from the bottom with increments of 10 cm to each side.

For similar velocity and pool depth conditions, two different forms of jet can be observed generally: a compact form (FORM a), which occurs most of the time and an unstable form (FORM b)[10]. The impact of a jet into a pool is governed by jet diffusion through a medium at rest. Momentum exchange with the pool creates a progressively growing shear layer, characterized by an increase of the jet's total cross section and a convergence of the core of the jet "Fig. 2". Dynamic pressures acting at the water–pool bottom interface can be generated by core jet impact, occurring for small plunge pool depths, or by impact of a fully developed turbulent shear layer, occurring for ratios of pool depth to jet thickness Y/Dj higher than 4 to 6. The exact Y/Dj ratio dividing these two regimes depends on jet outlet conditions and low-frequency jet stability. For the present study, the value of Y/Dj is below 5 and the obtained results are valid for this range.

RESULTS AND DISCUSSION

Dynamic Pressure at Plunge Pool Bottom: Pressure fluctuations on the pool bottom were measured in two directions perpendicular to each other. Sample of the maximum, minimum and mean measured pressure is shown in longitudinal and transverse directions due to variable width in "Fig. 3". As it was expected the maximum, minimum and mean pressure happens in the direction of center of impact jet and radially decreases. The range of influence of the jet at the center is similar for different widths (60 to 120 cm) while other variables were kept constant. At about 30-cm each side from the center

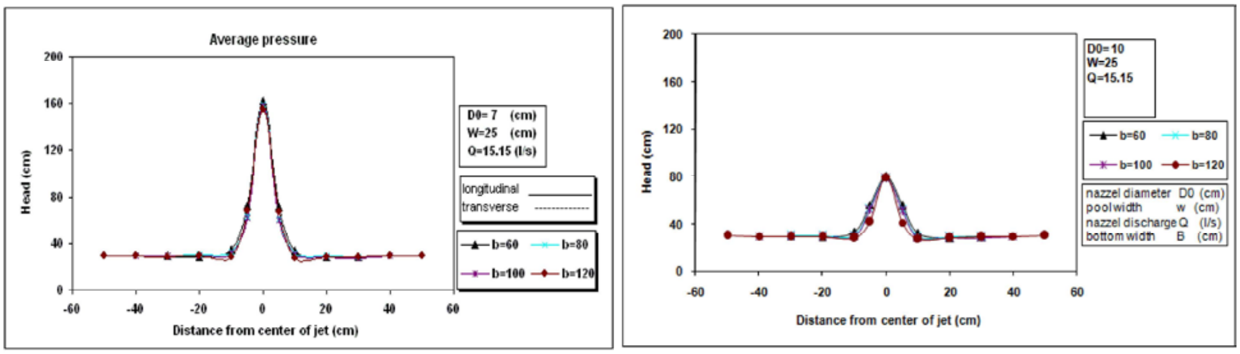

Fig. 3: *Plunging jets for jet core impact (for Y/Dj < 4–6)*

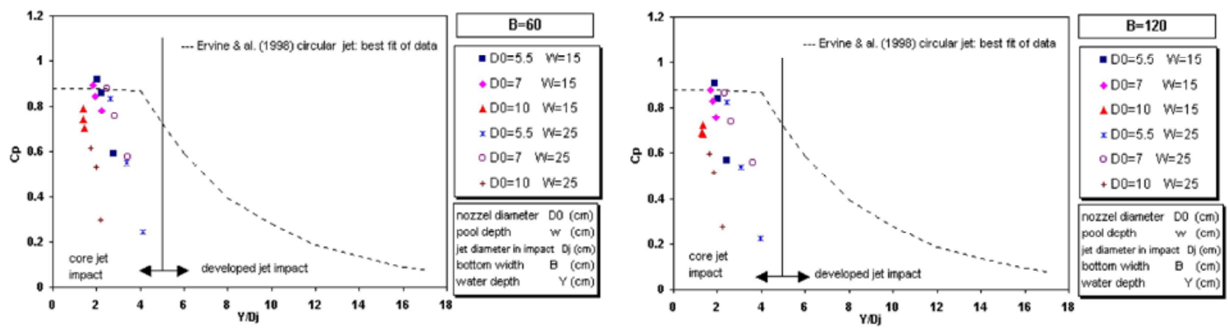

Fig. 4: *Variation of non-dimensional pressure coefficients with Y/D_j for core jet impact*

the pressure fluctuation is negligible. Also, before the hydrodynamic effect diminishes completely, a negative pressure is observed for all tests at a certain area. The effect was seen in all results while, for this figure the negative (or minimum) pressure happens at about 10-cm to both sides of the center. This is due to the wall jet effect, which has a high velocity near and tangential to bottom.

Mean Dynamic Pressure at Plunge Pool Bottom: The dimensionless *mean dynamic pressure* coefficient C_p is defined as a function of the mean dynamic pressure head H_m:

$$C_p = \frac{H_m - Y}{V_j^2/2g} \quad (1)$$

Where Y is water depth in pool H_m is dynamic pressure head and V_j is impact jet velocity. C_p has been analyzed as a function of the Y/D_j ratio (Fig. 4). Compares C_p with the best-fit curves of experiments made by Ervine *et al,* (1997). For core jet impact (Y/D_j<6), the measured C_p values are lower than the best-fit curves. This is probably due to the air entrainment on the present test facility. Also, occasional jet instabilities at low velocities (<15m/s), caused by the supply conduit, decrease the mean dynamic pressure. These results are in accordance with Bollert *et al.* (2003). The value of C_p decreases as Y/D_j increases as shown in Fig. 4. Different width (60 to 120 cm) has no effect on C_p. For Y/D_j=2.04, the maximum value of C_p is about 0.92. The importance of pressure fluctuations around the mean value is analyzed by means of the *root-mean-square (RMS)* coefficient C'_p. This coefficient expresses the RMS value of the dynamic pressure fluctuations, H (m), as a function of the incoming kinetic energy of the jet:

$$C'_p = \frac{RMS}{V_j^2/2g} \quad (2)$$

Sample of the variation of RMS on the plunge pool bottom with the Y/D_j is shown in (Fig. 5).

Extreme pressure values are described by the following dimensionless pressure coefficients:

$$C_P^+ = \frac{H_{max} - H_m}{V_j^2/2g} \quad (3)$$

$$C_P^- = \frac{H_m - H_{min}}{V_j^2/2g} \quad (4)$$

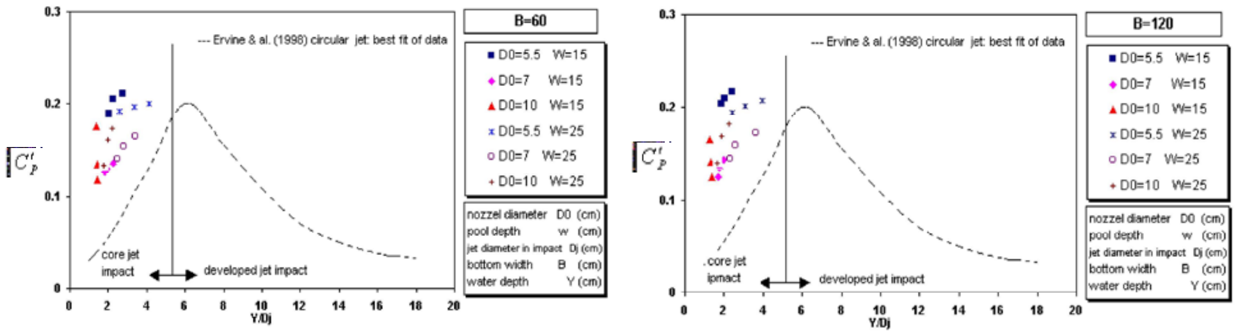

Fig. 5: *Variation of RMS coefficients with Y/D_j for core jet impact*

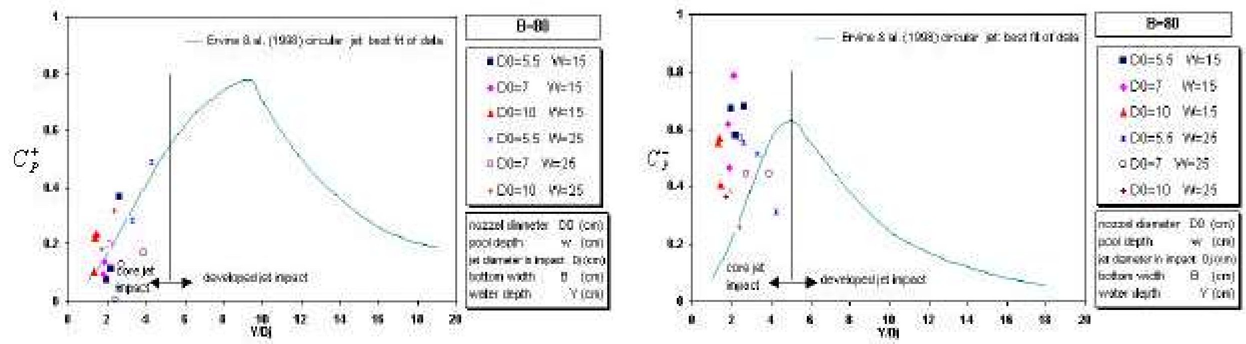

Fig. 6: *Variation of Extreme pressure values with Y/D_j for core jet impact*

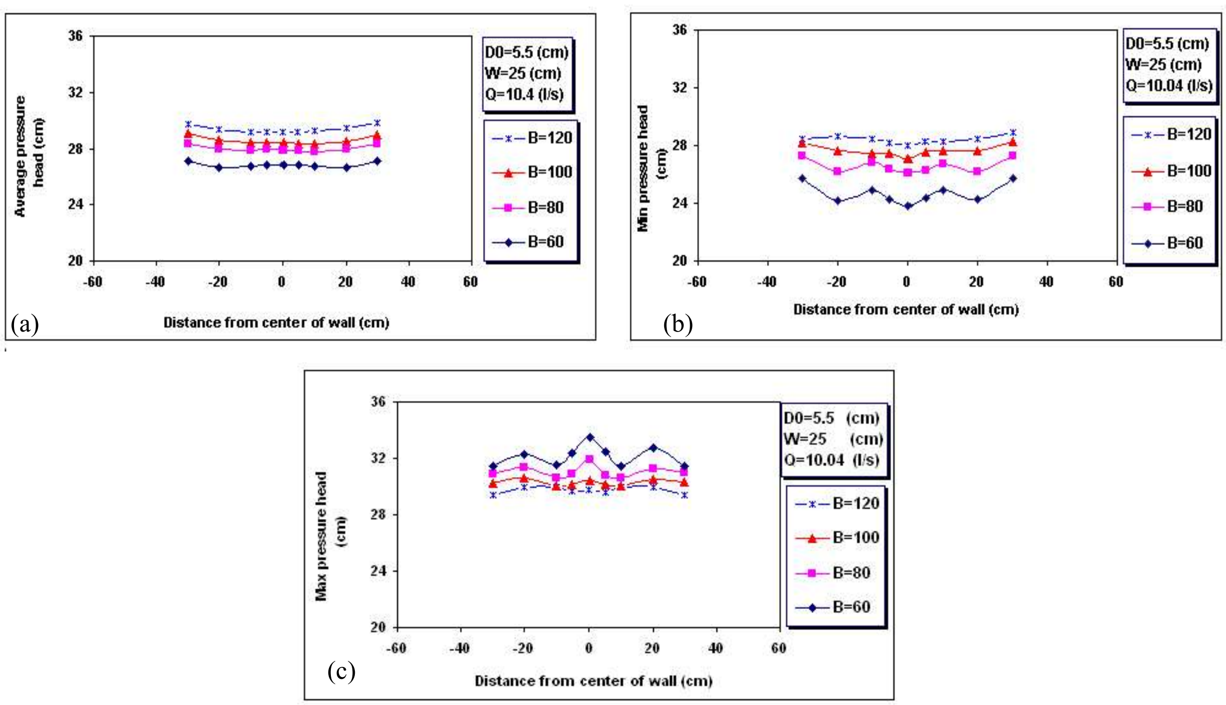

Fig. 7: *Pressure distribution on the plunge pool sidewalls due to circular jet impact and pool with: (a) Variation of average pressure; (b) Variation of minimum pressure; (c) Variation of maximum pressure*

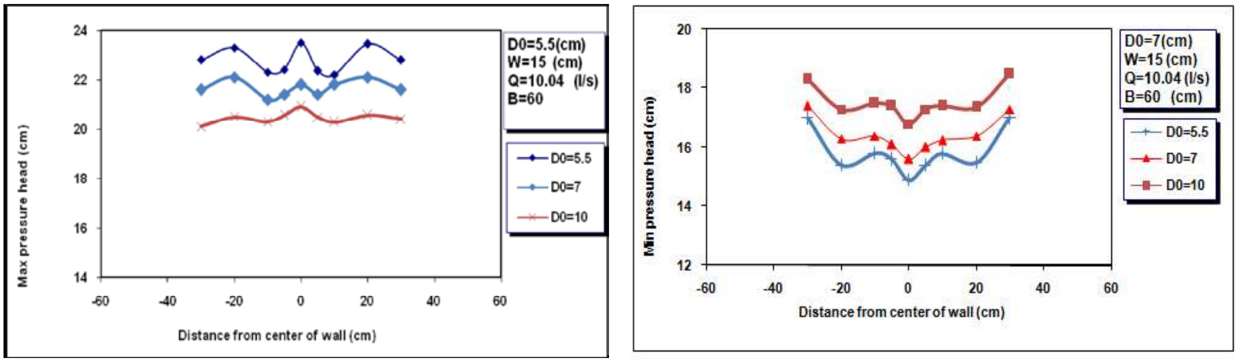

Fig. 8: Pressure distribution on sidewalls due to jet diameter (a) maximum pressure; (b) minimum pressure

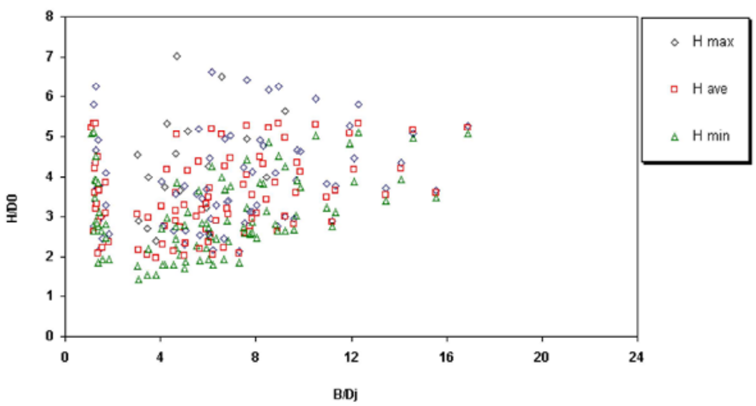

Fig. 9: Variation of non-dimensional coefficients B/Dj with H/D_0 for core jet impact in pool wall

With H_{max} and H_{min} the maximum and minimum measured dynamic pressure heads. Extreme positive values occur at Y/D_j atios of 10, in agreement with existing data (Ervine *et al*., 1997) (Fig.6). Extreme negative values occur for a Y/D_j ratio of 4 to 6, but stay more or less constant for lower Y/D_j ratios. This is in contradiction with the data by Ervine *et al*. (1997) these results are in accordance with Bollert *et al.* (2003).

Dynamic Pressures at Plunge Pool Sidewalls: Investigations on effect of pool width for circular core jet impact decrease the mean dynamic pressure on the walls (Fig.7a) and push it into negative region due to generating the wall jet and smaller size eddies. The circulation, which starts from the bed, has more effect on the wall if the pool width is smaller. On the other hand, for larger distance from the impact point the fluctuations become smaller and create a larger range of pressure fluctuations. Therefore the maximum pressure heads increases and the minimum pressure decreases (Fig. 7 b, c).

By increasing the jet diameter with similar width and velocities, the values of maximum dynamic pressure on wall decrease due to more wall jet effect on sidewall but minimum dynamic pressure on wall increasing (Fig. 8)

(Fig. 9) shows the non-dimensional variation of pressures (max, average and min) to water depth versus B/D_j with H/D_0. As it is seen, by increasing B/D_j, the maximum dynamic pressure decreases but the minimum dynamic pressure increases. At almost (B/D_j) =17 the pressure becomes equal and, the wall jet has lost its strength and influence and, only a small fluctuation of water surface exist.

According to this fact that greater wall slope cause sidewall to be closer to the impact jet. The results show effect of increasing sidewall slope on dynamic pressures on sidewalls has the same effect as decreasing bottom width. For core jet impact, mean dynamic pressure shows reduction.

CONCLUSION

The experimental results of variation of pressure in plunge pool due to pool size show;

- Dynamic pressure decreases in bottom of pool by increasing water depth in plunge pools due to high depth of jet penetration that causes to dissipation of jet energy.
- The maximum amount of mean dynamic pressure CP for Y/Dj=2.04 has obtained as 0.92.
- The maximum amount of dynamic pressure fluctuations RMS is 0.21 for Y/Dj=2.24.
- The maximum positive pressure is 0.5 for Y/Dj=4.10, while the minimum negative pressure is 0.8 for Y/Dj=2.25.
- The influence of more slender pool width on the sidewalls is to decrease the mean dynamic pressure. Also bye getting closer to jet impact zone, the minimum pressure decreases and the maximum pressure increases.
- By increasing the jet diameter with similar velocities, for core jet impacts, the values of maximum dynamic pressure on wall decrease due to more wall jet effect on sidewall but minimum dynamic pressure on wall increasing.
- By increasing wall slope, same effects on walls are deduced as narrowing the pool. For core jet impact, mean dynamic pressure shows reduction.
- By increasing B/Dj =17~18, the maximum dynamic pressure decreases but the minimum dynamic pressure increases.

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