DYNAMIC PRESSURE FLUCTUATIONS ON A TRAPEZOIDAL PLUNGE POOL SIDE WALLS AND BACKWALL DUE TO CIRCULAR AND RECTANGULAR WATER JETS

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Abstract - *Plunge pool is one of the energy dissipator structures downstream of dams, which form water cushion for the falling jet. Thus, the loss is due to the jet impacts the pool in the manner of macro- turbulent flow. In this way the excess energy of the jet is dissipated together with significant dynamic pressure exerted on the floor and pool sidewalls. While this kind of energy dissipator is quite popular for high dams, not much literature exists on the effects of pool's shape and geometry on hydrodynamic pressures of floor and sidewalls. So, this paper represents the experimental results of dynamic pressure variations measured with pressure transducers placed at plunge pool side walls, due to the impact of circular and rectangular water jets. Emphasis is given on the effect of geometry of the plunge pool, with a trapezoid section in plan view. The test variables include; discharge; geometry of jet, water depth in the pool, and different sidewall slopes. The results indicate the average pressure reduction due to core jet impact with sidewalls slope reduction while it increases in the case of developed jet impact. In both core and developed jet impact the maximum pressure on sidewalls increases and the minimum pressure decrease with side walls slope reduction [6]. Also, the preliminary investigations indicates two spots with local pressure on plunge pool back wall: one, the low pressure zone at the height of 0.4y and the other at the 0.6y from the floor which is a high pressure zone. The distance between the jet stagnation point and back wall location is an effective value in regards of pressure imposed to the back wall and it should be more meticulously investigated.*

Key Words: Plunge pool, Hydrodynamic pressure, Circular and rectangular jets, Core and developed jets, experimental model, Side walls, Back wall.

1. INTRODUCTION

Hydraulic structures with changing the uniform regime of the rivers will cause the nonbalancy of energy upstream and downstream of the structure. To set up that situation again some part of energy should be dissipated [1]. From the moment that jet comes out through the outlet some parts of its energy will be lost by friction and aeration and subsequently impact of the jet in the plunge pool, it's penetration and disintegration will form large recirculation, highly turbulent eddies and aerated shear layers which generate significant dynamic pressure fluctuation on the plunge pool floor and sidewalls [2,7]. Characteristics such as non-homogeneity, non-Isotropy and 3D mutations of turbulent flow in energy dissipator structures and also difficulties in calculation and determination of fluctuating pressure in these structures are the hindrances for precise analytical researches. In this case, using hydraulic models is one of the practical solutions to investigate hydraulic parameters such as hydrodynamic pressure [5,6]

The mechanism of energy dissipation and the assessment of dynamic pressures in plunge pools have been studied by many researchers during the two last decades, such as; Castillo et al. (1991), Ervine et al.(1997), Peiqing et al.(2001), Bollaert & Schleiss (2003-2004), Melo et al.(2006)[3]. Not much literature exists on the effects of pool's shape and geometry on hydrodynamic pressures of floor and sidewalls. In 2004 Zarnani has done some researches on the effects of plunge pools width and its side wall's slope in dynamic pressure distribution. His research in initial ways has answered some of the questions in this field. But still there are lots of questions. Such as, what if the plunge pool is not rectangular and the width will change at the plan as it really happens at in the valleys. In that case, How is the dynamic pressure distribution and the flow pattern [6,7].

To complete the researches that have been done until now, in this research with using pressure transducers with the ability in registration and documentation of fluctuating dynamic pressures and an experimental model, distribution of mean and extreme dynamic pressures at the sidewalls and back wall of the plunge pool due to the impact of circular and rectangular jets at the plunge pool has been observed, and the parameters are Discharge, Diameter of circular jet, Dimension and ratio of width to length of rectangular jet, Depth of water at the plunge pool, bottom width and side walls slope in plan. At the end, after the introduction of experimental instruments of this study, the 1D & 2D pressure distribution plots at the sidewalls and back wall of the plunge pool has been depicted and the conclusion on the effect of pool geometry on walls imposed pressure has been revealed [6].

2. EXPERIMENTAL APPARATUS AND INSTRUMENTATION

The experimental apparatus and measurements consist of nine main parts (Fig 1, 2). Water runs in a circuit and pumps from a ground tank into an air tank at the top of the Plexiglas 60 cm length plunge pool model which then impacts the water cushion of the pool as a free impinging jet. Water jets are in different shapes (circular and rectangular) with different dimensions (D_0 for circular and A_0, B_0 for rectangular) and different discharges (In the range of 3.5 to 20.5 l/s and maximum velocity of 4.34 m/s). The slopes of side walls, (S=H/V; S=length of plunge pool in the direction of outflow/ width change at perpendicular direction of outflow) that has been investigated in this research are; ∞ or without slope, 4:1, 3:1 and 2:1(Fig 3). The depth of water (Y) is 20 and 50 cm in order to simulate core and developed jets. Overall, 288 tests with record duration of 1 min were carried out to assess the dynamic pressure fluctuation using pressure transducers with sampling rate of up to 1.5 KHZ [6]. (Table 1).

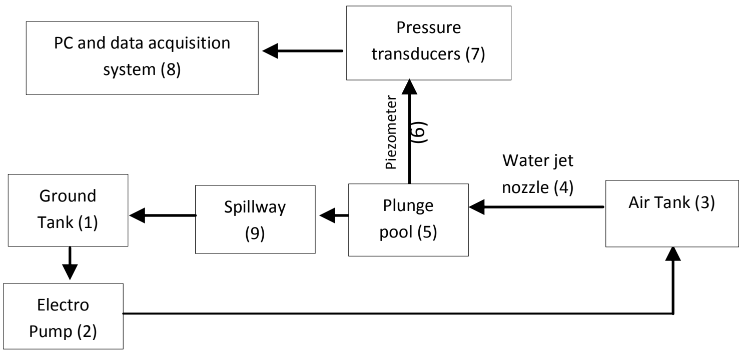

Fig-1: Schematic sketch of Laboratory Apparatus and Instrumentation (6)

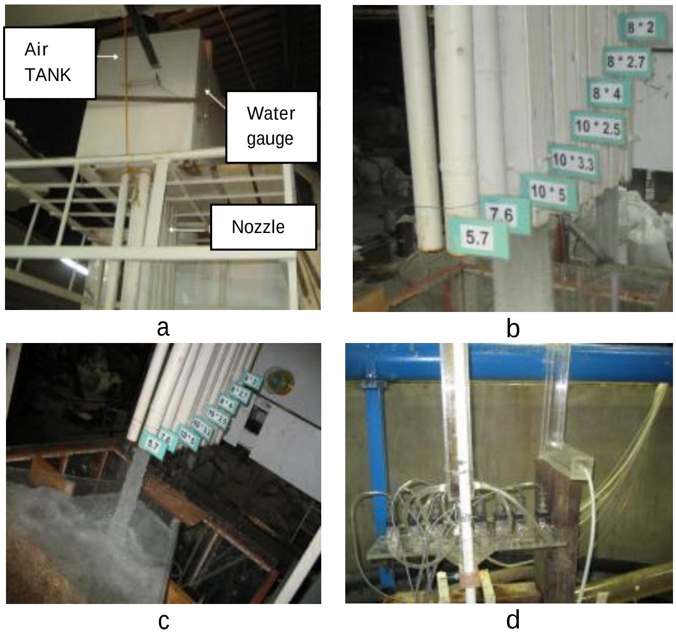

Fig-2: a) Air tank b) Nozzles c) Plunge pool d) Pressure transducer [6]

Table-1: Experimental Parameters and number of tests [6]

Jet Type	Nozzle Dimension	With/ Length ratio	Pool Depth	Side wall Slopes	Water Height in tank	Runs
	D_0 or A_0 (cm)	B_0/A_0	Y (cm)	S=H/V	H (cm)	No of runs
Circular	3.9,5.7,7.6	-	20,50	2:1 , 3:1 , 4:1 , ∞	36,51,61,71	96
Rectangular	10,8	1/2 , 1/3 , 1/4	20,50	2:1 , 3:1 , 4:1 , ∞	36,51,61,71	192

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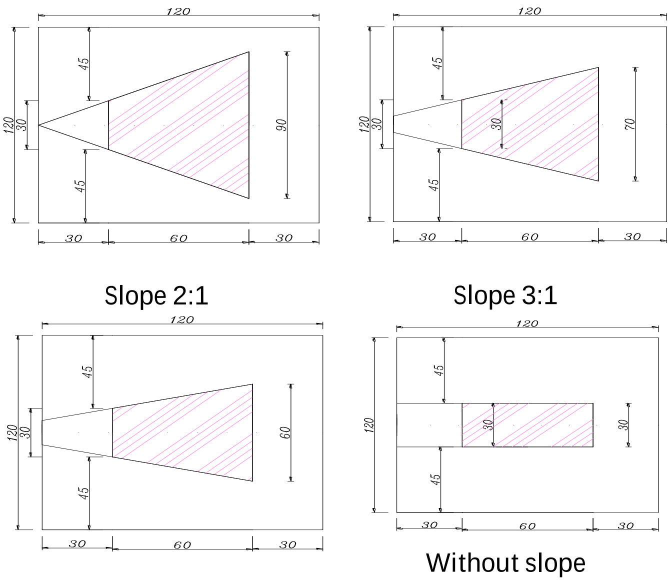


Slope 2:1 Slope 3:1

Slope 4:1 Without slope (Rectangular pool)

Fig-3: Sidewall slope in plan [6]

The piezometer tabs in sidewalls were located at a distance of 10 cm in depth of the plunge pool direction while their distance at the horizontal direction were different based on sidewalls slope from 10 cm in rectangular pool to 11.2 cm in 2:1 sidewalls slope. For the backwater there was a more condensed piezometer tab sorting. The piezometer tab distance in horizontal direction was 5 cm while in perpendicular direction it was 10 cm.

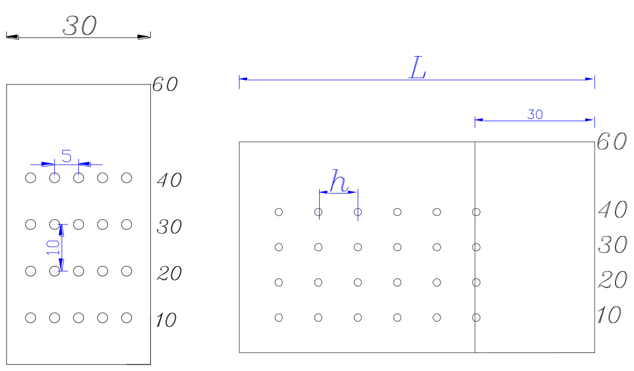
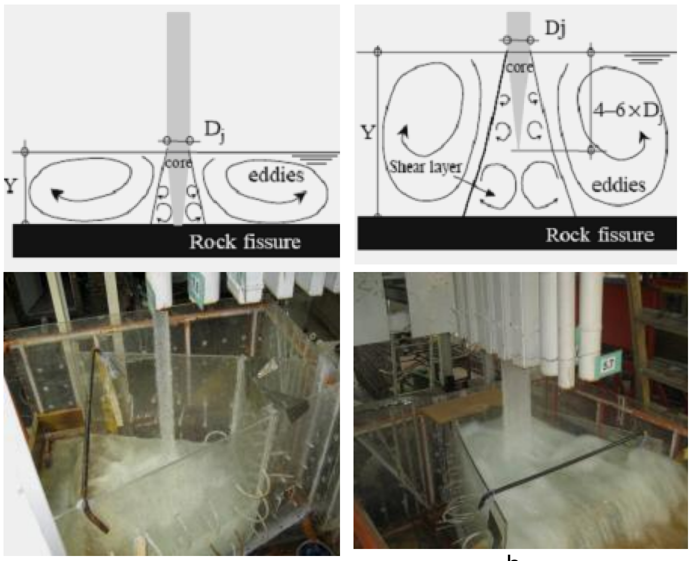


Fig-4: Piezometer tab sorting in sidewalls and back wall of the plunge pool [6]

3. JET DIFFUSION REGIMES IN PLUNGE POOL

Because of decreasing momentum instead of increasing shear layer thickness, the velocity of impinging jet in to the stagnant water, considered to be monotonous. In shear layer area of jet increases and reciprocally triangular core decreases [4]. With this theory dynamic pressure acting on the water-bed interface can be generated by core jet impact, for small plunge pool depths, or by impact of a fully developed macro turbulent shear layer, in ratios of plunge pool depth to jet thickness $\left(\frac{y}{D_j or B_j} > 4-6\right)$ Which D_j and B_j are the water jet dimensions in impact with water surface. Also, dynamic pressure exerted on sidewalls especially can be formed by turbulent eddies, re-circulations and also wall jet effect on sidewall especially in core jet impacts $\left(\frac{y}{D_j or B_j} < 4-6\right)$ [3].

In this study Y/D_j between 2 and 12.5 for circular jets and Y/B_j between 2.5 and 18 for rectangular jets has been tested which contain both core and developed jet diffusion regimes (Figure 5) [6].



a b

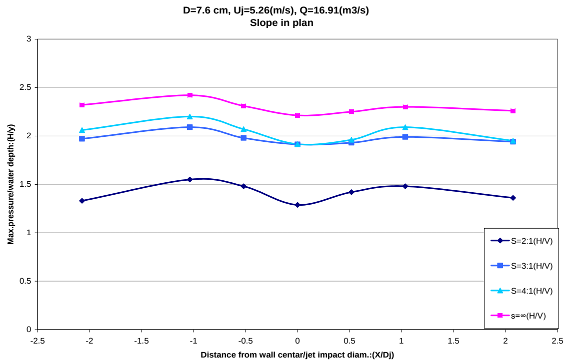
Fig-5:Jet diffusion regimes; a) Core jet, b) Developed jet [6]

4. RESULTS

4.1 Pressure distribution at plunge pool sidewalls

The pressure distribution at the height of 10 cm from the floor (which has the most pressure oscillation) has been investigated and the plots below show some sample of the results for mean, maximum and minimum of the measured exerted pressure on the sidewalls.

4.1.1 Maximum hydrodynamic pressure pattern



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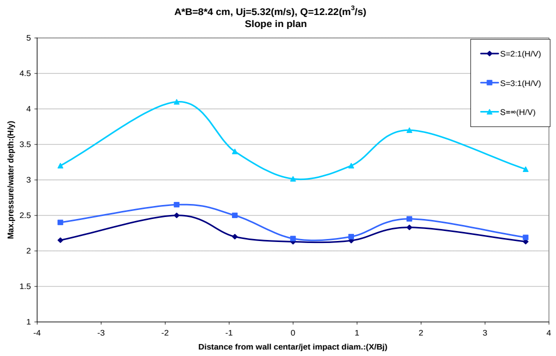

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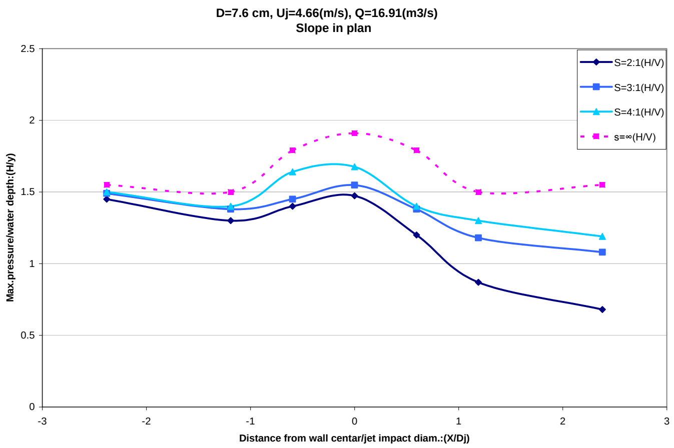
Chart-1: Maximum Pressure distribution at the height of 10 cm a) Circular impinging core jet b) Rectangular impinging core jet [6]



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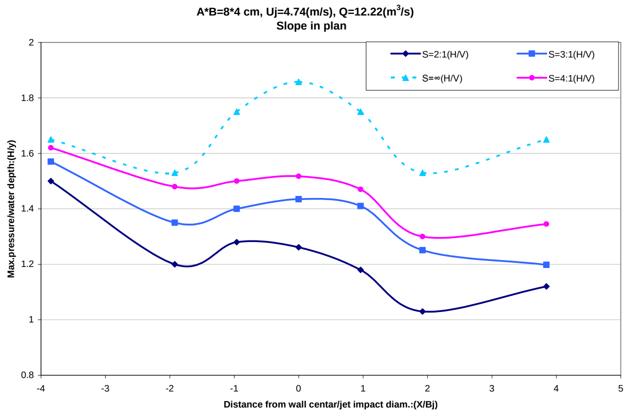
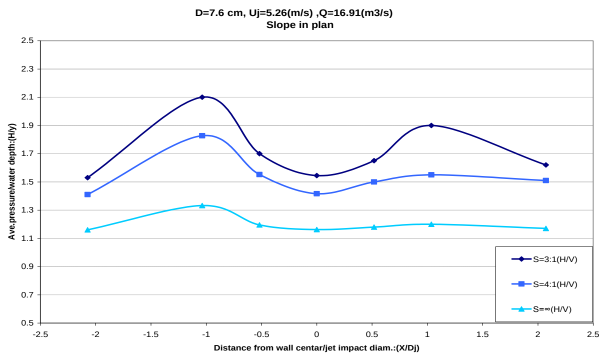


b)

Chart-2: Maximum Pressure distribution at the height of 10 cm a) Circular impinging developed jet b) Rectangular impinging developed jet [6]

Based on observations, because of the more circular jet effect on the sidewalls in core jet impact, the minimum pressure occurs at the stagnation point location while in developed jet impact due to the diminished radial jet effect, the most pressure on sidewalls is exerted at the stagnation point. It is also evident that the maximum measured pressure at the sidewalls decreases with increasing sidewalls slope. That is because of the width growth with increasing sidewalls slope and reduced pressure oscillation on the sidewalls. Based on the previous studies the maximum pressure increases with decreasing of the plunge pool width [7] that's why there is a nonsymetry in the pressure distribution plot in the flow path direction and this phenomena is more obvious in developed jet regime due to the larger eddies scale.

4.1.2 Average hydrodynamic pressure pattern



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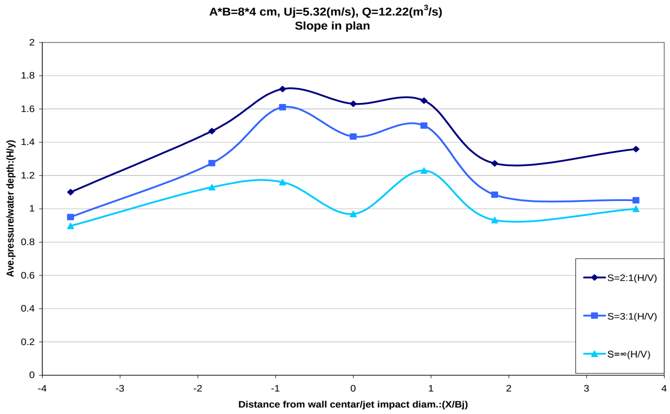
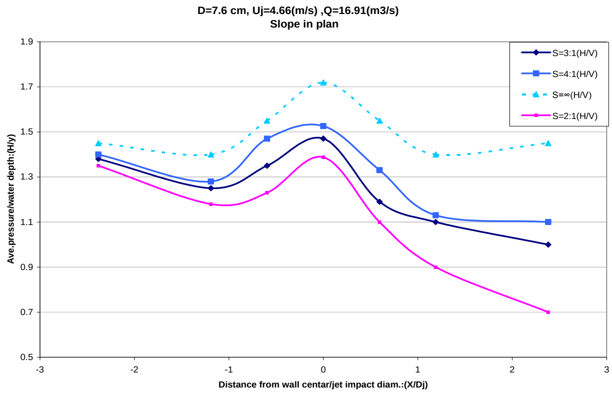


b)

Chart-3: Mean Pressure distribution at the height of 10 cm a) Circular impinging core jet b) Rectangular impinging core jet [6]



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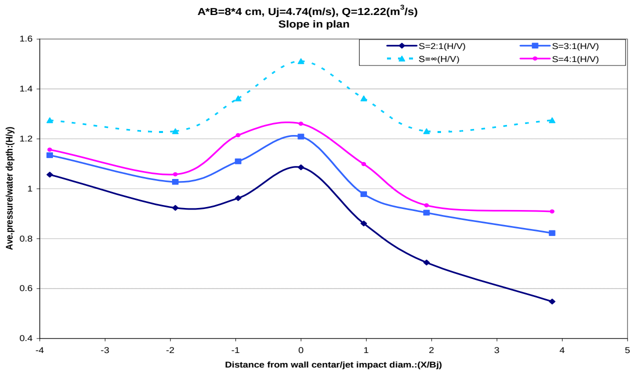
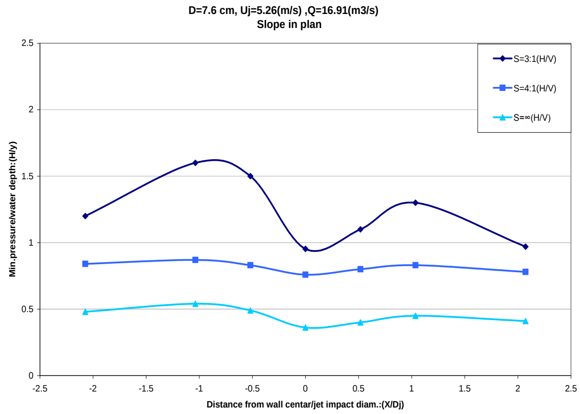


b)

Chart-4: Mean Pressure distribution at the height of 10 cm a) Circular impinging developed jet b) Rectangular impinging developed jet [6]

Based on observations, the measured average pressure on the sidewalls decreases with sidewalls slope deduction and that's due to the negative pressure effect of radial jet on the walls in core jet regime. On the contrary, for developed jet regime that there is a more pressure alleviation and radial jet becomes less effective, the walls slope reduction leads to more average pressure on the walls. Like the maximum pressure, the nonsymetry of pressure distribution at the flow direction is quite clear in developed jet regime with larger eddies and turbulence scale of flow. Also the average pressure at the stagnation point in core jet regime is minimum while in developed jet situation is the top of the diagram.

4.1.3 Minimum hydrodynamic pressure pattern



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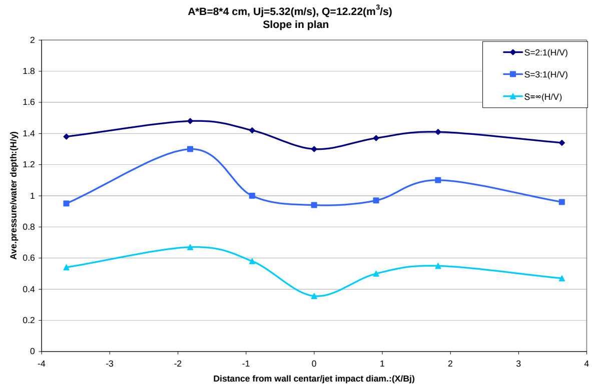

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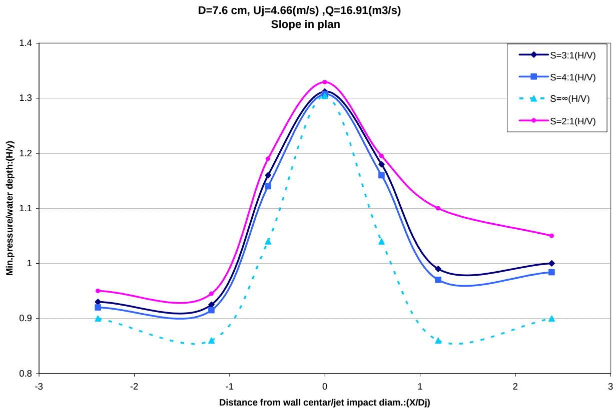
Chart-5: Minimum Pressure distribution at the height of 10 cm a) Circular impinging core jet b) Rectangular impinging core jet [6]



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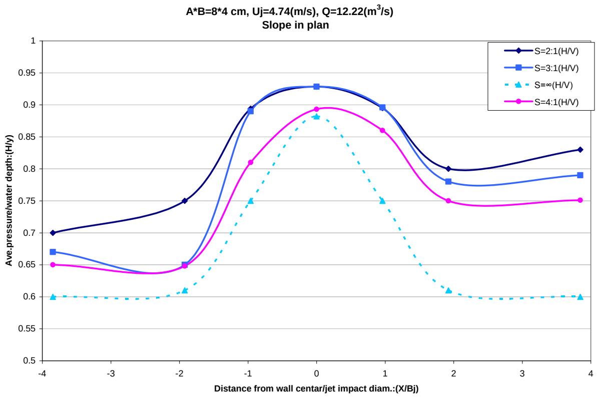


b)

Chart-6:Minimum Pressure distribution at the height of 10 cm a) Circular impinging developed jet b) Rectangular impinging developed jet [6]

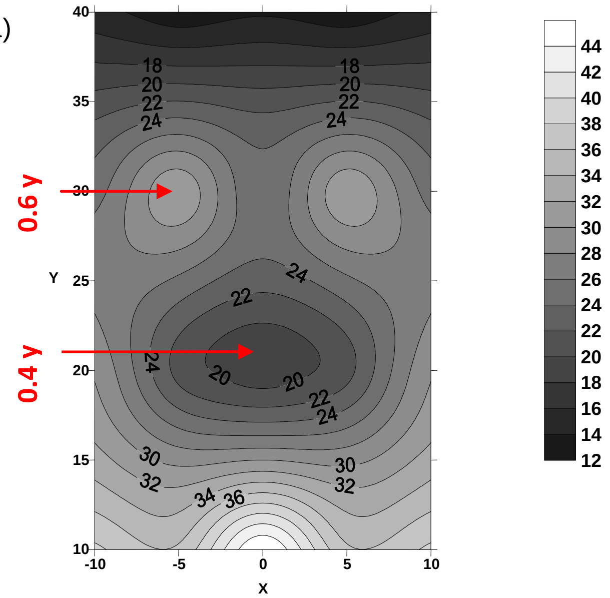
Based on observations, in both regime of water jet (core and developed), the reduction of exerted pressure on the sidewalls with reduction of slope and width has been observed and that is because of oscillation amplitude growth with reduction of slope and consequently the width of the pool which means more difference between extreme pressures. In other words, increase of the maximum and decrease of the minimum pressure. Also the minimum pressure at the stagnation point in core jet regime is minimum while in developed jet situation is the top of the diagram.

4.2 Pressure distribution at plunge pool backwall

Hydrodynamic Pressure at the backwall of the plunge pool has been measured by pressure transducer in each 10 cm of the wall. Isobaric maps dedicate a low pressure zone at the height of 0.4y of the pool and two high pressure zones at the height of 0.6y of the pool.

The pressure algorithm at the wall is complicated based on the facts that: 1) Increase in pool water level reduce the pressure 2) The pressure decreases in higher portion of the wall due to the increasing distant from stagnation point while 3) Due to the fact that the core of the jet penetrates in water and after a distance the core diminishes and the jet becomes as a developed one, the increase of the height may result in the growth of the pressure. So there is not a specific algorithm for that and it is a complex phenomenon.

a)



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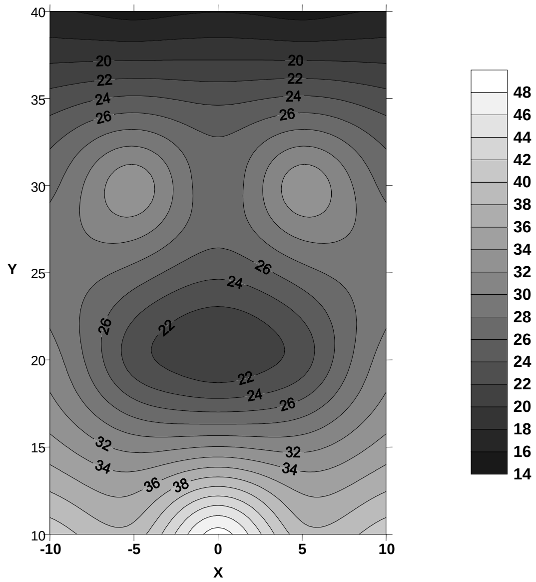

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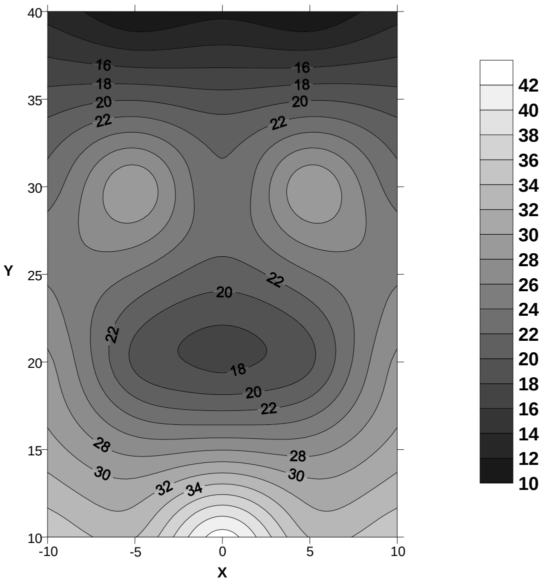

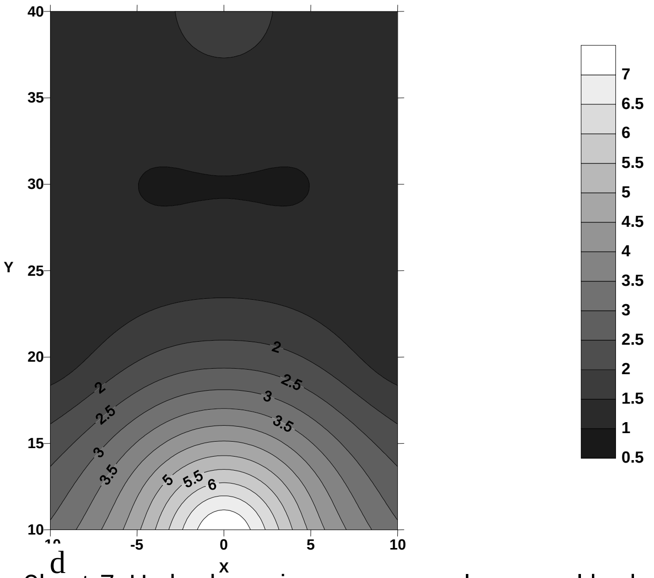

d

Chart-7: Hydrodynamic pressure on plunge pool backwall due to the 7.6 cm developed jet impact and side wall slope 2:1 a)Average pressure b)Maximum pressure c) Minimum pressure d) RMS[1] of pressure fluctuation. Point (0,0) is at the stagnation point direction

5. CONCLUSION

Hydrodynamic pressure on pool sidewalls:

1-In both jet regime (core and developed jet) with decreasing the sidewall slope and consequently the pool width, the pressure fluctuation amplitude increase which leads to the increasing maximum pressure and decreasing minimum pressure exerted on the walls.

2- With decreasing sidewall slopes and of course the pool depth, in core jet impact, due to the effectiveness of negative pressure arising from radial jets, the average pressure decrease whereas for developed jet impact with more water cushion thickness the water energy alleviates and the average pressure exerted on the wall increases.

Hydrodynamic pressure on pool backwall:

1-In (0,0) position of the backwall based on the closeness to the stagnation point the amount of maximum, average and minimum of the pressure is at the highest value.

2-At the height of 0.6*y from the floor - location where core jet converts to developed one-two symmetric high pressure zone observed while at the height of 0.4*y from the floor a low pressure zone has been observed.

3-Hydrodynamic pressure fluctuation has a radial pattern and diminishes with the distance from the stagnation point.

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[1] Root Mean Square

BIOGRAPHIES

Sima Safarkhani was born in Tehran, Iran, in 1981. She received B.S in civil engineering from IUST university in 2004 and M.S in civil engineering from Sharif University of Technology in 2007. Her main area of research are river and hydraulic structure modelling, water resource management, LID and BMP techniques, and WSUD.

Prof. Seyyed Mahmood Borghei was born in Tehran, Iran, in 1954. He received B.S. and Ph.D. degrees in Civil Engineering and in Hydraulics Engineering, in 1977 and 1982, respectively, from Nottingham University, UK. He has been a Professor in Sharif University of Technology, Tehran, Iran, since 2006. His main research interests included experimental and physical modeling of hydraulic structures, and river engineering, and he has had more than 120 papers published in scientific journals and conference proceedings in these areas. He has also supervised more than 50 M.S. and Ph.D. degree students.

