Total Pressure around Chute Blocks of SAF Stilling Basins

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Abstract: *Induced total pressure by flow, including mean and fluctuating components, around a selected chute block in SAF stilling basins downstream of an ogee spillway was studied. Several pressure holes were selected on various faces of a selected chute block to get enough information regarding the total pressure field. This paper reports the results of an experimental work and measurement of mean and fluctuation pressures around chute blocks of SAF stilling basins. The observations showed that the maximum total pressure varies inversely with Froude number of incoming flow while its position of occurrence follows a quadratic polynomial relationship. Statistical analysis also showed that the peak instantaneous pressure fluctuations could be as large as ±4.5times the RMS value.It is concluded that pressure fluctuation around the chute blocks may double the magnitude of pressure field around the chute blocks and can not be overlooked in designing such appurtenances.*

Keywords: *SAF stilling basin, chute blocks, pressure field, pressure fluctuation, submergence ratio*

1. Introduction

Hydraulic jump prevails at downstream of hydraulic structures such as spillways, sluice gates and chutes whereby a supercritical flow with high kinetic energy occurs and may endanger the stability of such structures. Precautions have to be taken in designing the stilling basins and their appurtenances encountered with these structures. In general, the mean velocities and hydrostatic pressures are considered in designing the stilling basins and their appurtenances such as chute blocks, baffle blocks and end sills. It is quite evident that the presence of strong turbulent flow would not endorse the over mentioned procedure because of the action of prevailed fluctuating characteristics. It is also known that the fluctuating pressures/forces would weaken the structure by the action of fatigues which may arise as the consequences of fluctuating pressures/forces. Therefore, the measurement of fluctuating pressure/forces may not be too easy to measure at site. Therefore, it seems to be useful if the characteristics of mean and fluctuating pressure /force at stilling basins and around their appurtenances to be studied.

Saint Anthony Falls (S.A.F) stilling basin is one of the compacted energy dissipaters which was designed and suggested by Blaisdell, [1&2] and investigated in Saint Anthony Falls Laboratory on the base of mean flow characteristics and is frequently used in water conveyance systems with wide range of Froude numbers ranging from 1.7 to 17. Harleman, [3] was one of the pioneers who assessed the role of baffle blocks in functioning of stilling basins and their effects on flow characteristics. Basco and Adams, [4]studied the field of drag force in the hydraulic jump. Karki ,[5] investigated the mean pressure on upstream face of an end sill in stilling basins and reported valuable information in relation to the influences of hydraulic jump position from the end sill on pressure distribution profiles .Tyagi *et al*,[6] reported the effect of drag force on baffle blocks. Narayanan and Schizas, [7] studied the influence of induced force by hydraulic jump on the end sill in a USBR type II basin. Rouse *et al*., [8] widely studied the turbulent characteristics of hydraulic jump using the transport equations which paved way to assess the rat of energy dissipation through the phenomenon. Analyzes of mean pressure pattern and flow characteristics were studied and reported by Ohtso *et al*.,[9]. Farhoudi and Narayanan, [10] carried out a set of experiments to study the field of drag force induced by hydraulic jump on baffle blocks in a stilling basin downstream of sluice gate. Firotto and Rinaldo,

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[11]studied the features of hydraulic jump downstream of sluice gate where the Froude number was ranging from 5 to 9.5. Farhoudi and Volker, [12] studied the pressure field around a cubic baffle block in stilling basin downstream of spillway and analyze d the effective mean pressure distribution. The function of induced dynamic force in stilling basins was experimentally measured and reported by Bellin and Firotto, [13]. V.Armenio *et al*., [14]alstudied the induced pressure fluctuations by a negative step at bottom of hydraulic jump. Guven, A.,Gunal,M. and Abdulkadir, C,[15] utilised the neural network to predict the pressure fluctuations in sloping stilling basins.. Farhoudi *et al*., [16] conducted a research program to investigate the characteristics of pressure fluctuations around chute blocks of SAF basins. They concluded that the maximum pressure fluctuation would follow a decaying exponential relationship with Froude number of incoming supercritical flow and a polynomial relationship with submergence ratio of hydraulic jump.

The reviewed literatures reflect that the fluctuating pressure may endanger the stability of compacted energy dissipaters which can not be overlooked in designing such structures. On the other hand enough information is not reported so far. Therefore, flow induced total pressure, including mean and fluctuating components, around a selected chute block in a SAF stilling basins downstream of an ogee spillway was studied and the details are outlined to contribute some information for engineers in designing the appurtenances of such stilling basins.

2. Experimental layout and procedure

The experiments were conducted in a laboratory glass walled flume of 25cm width, 30 cm height and 600 cm length .An ogee spillway of 40 cm height equipped with a SAF basin with 5 chute block(4 cm height,3 cm width and 8 cm length),4 baffle blocks and a solid end sill of 2cm height were designed according to Blaisdell, [1&2] recommendations and erected at a distance of 100 cm from the entrance tank of the flume which is shown in (Fig.1). Assuming a symmetrical flow pattern in the flume, a chute block was selected at the centreline and 26 pressure holes were then drilled on its different faces as is depicted in (Fig.2). A Druck type pressure transducer was used to detect the pressure fluctuation .All pressure holes were connected to pressure transducer by means of a transparent plastic hose and the measurements were then recorded by a rate of 100 samples per second. The information was then transmitted to an AD converter and analyzed using View Dec software.

Prior to experiments, different length of transparent pipe connections to some pressure holes are tested to achieve a steady state pressure reading from which a length of 50 to 120 cm was

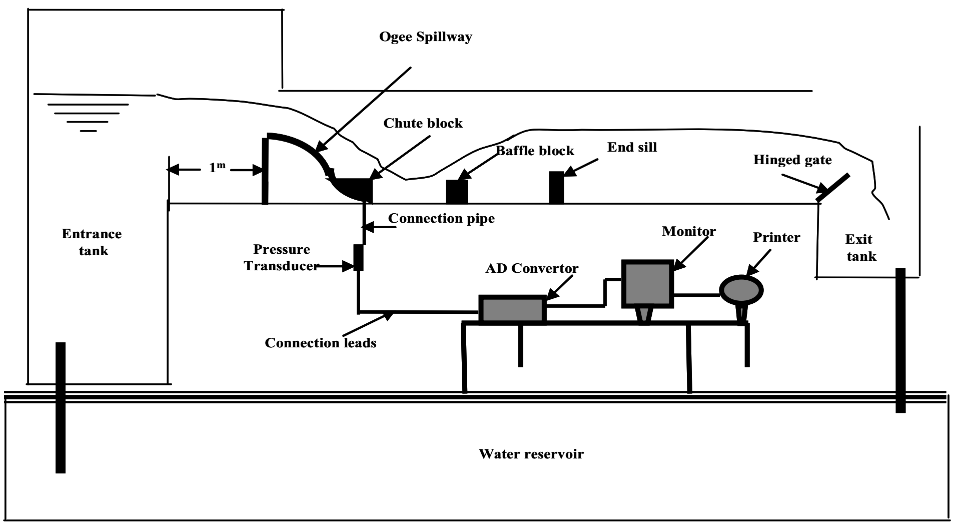


Fig. 1. Experimental layout (Not in scale)

recorded. The acceptable time length for data acquisition was selected as 120 second from oscilloscope readings. The rating curve of spillway was achieved by measuring the flow height over the crest and discharge using a pre-calibrated rectangular sharp crested weir at downstream of the flume. The flow discharge was ranging from 17.93 to 104.2 lit/sec (Froude number ranging from 5.5 to 12) where the submergence ratio varying from 0 to 100%, at intervals of 10%. A hinged gate was installed at downstream end of flume to control the flow depth throughout the reach for desired submergence ratios.

3. Experimental Designs

Considering the governing geometry of the structure and flow characteristics the total pressure around the chute blocks could be affected by the following parameters:

p& p'= mean pressure and pressure fluctuation, respectively,
d_1= supercritical incoming flow depth,
T_w=tailwater depth,
v_1 = mean flow velocity of incoming flow,
ρ =mass density of flow (water),
μ =flow viscosity,
g =gravitational acceleration, and
L_B=the length of stilling basin,
H, B and L=height, width and length of the chute block, respectively,
β =the coverage ratio of chute blocks,
x,y,z =Cartesian coordinates of each hole from origin O in Fig.2,

Therefore, the total pressure would be defined as:

$$F\,[(p+p'),d_1,v_1,T_W,\rho,\mu,g,L_B,\beta,H,B,L\ x,y,z)=0 \qquad (1\text{-}1)$$

Taking recourse from Buckingham's theorem, the following non-dimensional parameters would be concluded to define the total pressure fluctuations around the experimental chute block:

$$(C_p+C'p)=\varphi_1\,(F_1, R, S_d, x/d_1, y/d_1, z/d_1) \qquad (1\text{-}2)$$

where:

$C_P=\dfrac{p}{\frac{1}{2}\rho V^2}$ =Coefficient of mean pressure,

$C'_p=\dfrac{\sqrt{(\overline{p'^2})}}{\frac{1}{2}\rho v^2}=\dfrac{\text{RMS}}{\frac{1}{2}\rho v^2}$ =Coefficient of pressure fluctuation, $C_p+C'_p$ =Total pressure field, p=Mean hydrostatic pressure= γ h, p'=Measured pressure fluctuation, v=Flow mean velocity,

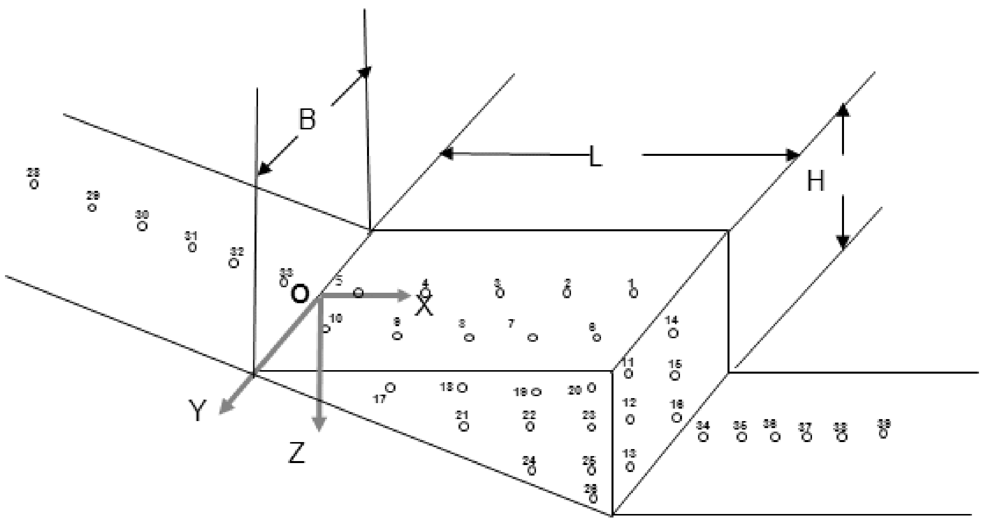


Fig. 2. Position of pressure holes around the selected chute block

γ=specific weight of water, ρ=Mass density of water, F_1= Froude number of incoming flow at the toe of spillway, *h*=active water depth over the pressure holes, *R*=Flow Reynolds number, *RMS*=Root Mean Square, S_d=Submergence ratio=[$(Tw/d^2)-1$], x, y and *z*=Cartesian coordinates of each hole from origin *O* in Fig.2, d_1 and d_2=flow depth at the toe of hydraulic jump respectively, and T_w= Tailwater depth.

Since $R>10^4$ throughout the experiments, eqn. (1) would be simplified as:

$$(C_p+C'_p)=\varphi(F_1, S_d, x/d_1, y/d_1, z/d_1) \quad (2)$$

Eqn.(2) was utilized throughout the investigation.

4. Analysis of Results

To give a best realization from the total pressure field at different positions around the experimental chute block, the related observations at each face of the block as well as its upstream and downstream flow reach would be discussed separately at the following sections.

Observations of total pressure field along the upstream to downstream of chute block for different F_1 and $S_d=0$, are depicted in Fig. 3. As it clear from the figure, the magnitude of total pressure field at the face of spillway increasing towards of its toe independently from F_1 values.At interface of spillway with chute blocks the pressure field reaches its peak varying in magnitude and position with F_1 values. It is also observed that the peak pressure field values $[(C_p+C'_p)]\ m$, are followed with a second peak with smaller values at downstream of the toe which decays as F_1 increases. The close assessment in $(C_p+C'_p)\ m$ values and its positions of occurrence, showed that the variation of $(C_p+C'_p)\ m$ values with F_1 falls in a decaying power function with a level of confidence R^2=0.975 as:

$$(C_p+C'_p)_m = 5.263(F_1)^{-0.9895} \quad (3)$$

The position of $(C_p+C'_p)\ m$ occurrence (X_m) follows a quadratic polynomial relationship between with the Froude number of incoming flow to the stilling basin at a level of confidence of R^2=0.965 which is expressed as:

$$X_m=A_1(F_1)^4+A_2(F_1)^3+A_3(F_1)^2+A_4(F_1)+A_5 \quad (4)$$

where A_1, A_2, A_3, A_4 and A_5 are constant parameters as are tabulated in (Table 1).It is also observed that the component of fluctuating pressure may contribute between 0.44 to 2.11 times of mean pressure to total field at

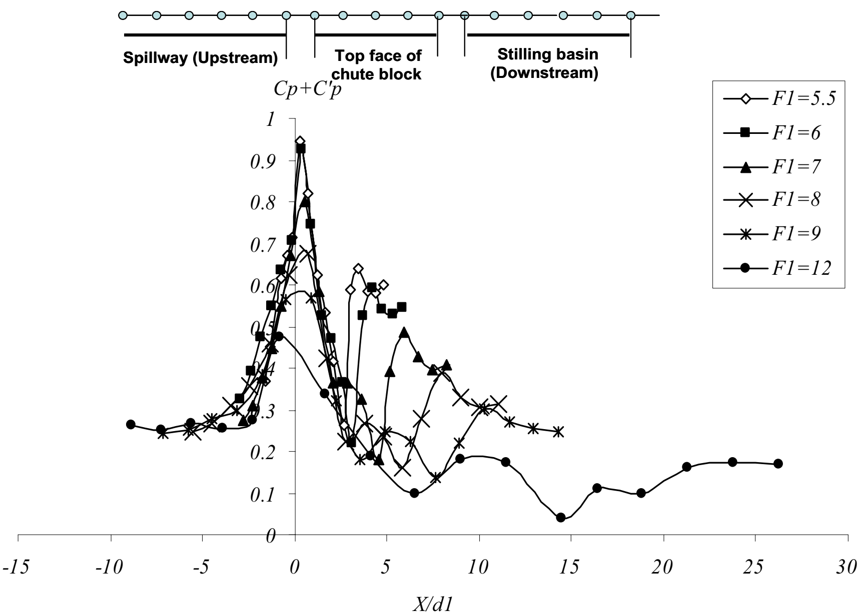


Fig. 3. Variation of $C_p+C'_p$ with F1 for Sd=0, at the flow direction throughout of upstream to downstream of chute block

Table 1 Parameters of equation (4).

Parameter	A_1	A_2	A_3	A_4	A_5
Values	0.0141	-0.4881	6.1129	-32.736	63.837

downstream foot of chute blocks (pressure hole 34 at Fig. 2).The percentage of pressure increase is in an adverse relationship with F_1.

Influence of tailwater depth (S_d) on total pressure field is plotted in (Fig. 4) for F_1=8. The sketch verifies the universal trend of (Fig. 3) and shows while the position of peak values stands fixed it shows an increasing trend of ($C_p+C'_p$) with submergence ratio.

Close observation on (Fig. 4) reveals that the ($C_p+C'_p$) *m* values fit in a polynomial equation with S_d as is expressed by equation (5).

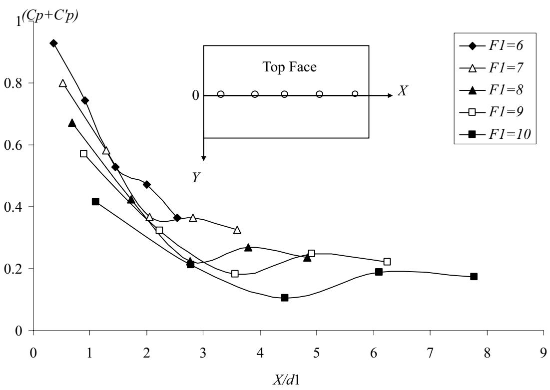
$$(C_p+C'_p)_m = -0.297(S_d)^2+0.429(S_d)+0.667 \quad (5)$$

Equation (5) fits the observations with a confidence level of R^2=0.96.

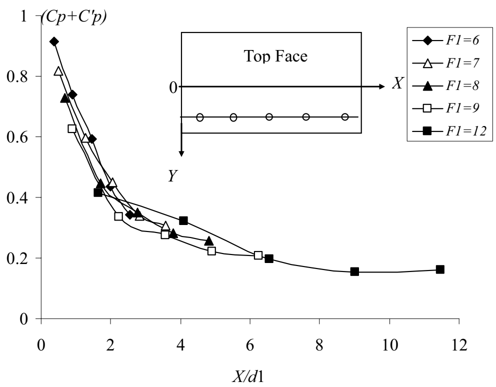
Variation of ($C_p+C'_p$) with F1 at top face (XY Plane), *Y*=0 and *Y=B/3*, is shown in (Fig. 5).It is noticeable that the total pressure is following decaying trend at flow direction and as the F_1 values are increasing the curves become flattered. The effect of F_1 values on total pressure becomes almost un-significant at *Y*-wise towards the edge of the block as can be seen in (Fig. 5) for *Y=B/3*, where the variation could be defined by a unique power function as:

$$(C_p + C'_p) = 0.6075(F_1)^{-0.5568} \quad (6)$$

ration on total pressure is demonstrated in (Fig. 6). It is observed that at low tailwater depths the total pressure changes in a trend similar to that was shown in (Fig. 7). However, as the S_d values increases the trend of total pressure variation tends to become flattered. It is also indicated that the trend is tending to become almost decaying



(a)



(b)

Fig. 5. Variation of $C_p+C'_p$ with F_1 for S_d=0, in XY-plane (a): *Y*=0 and (b): *Y=B/3*

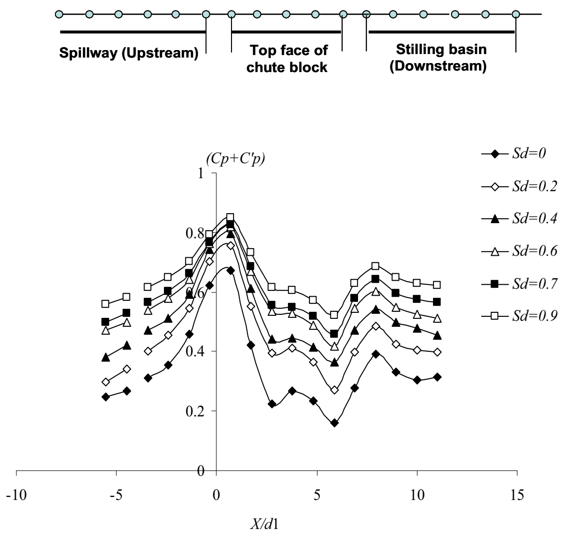
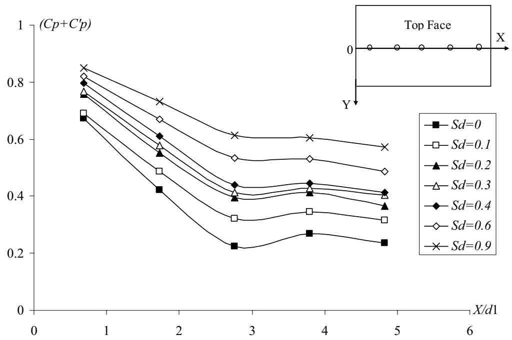
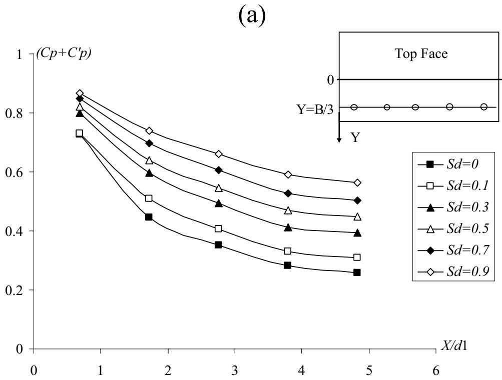


Fig. 4. Variation of $C_p+C'_p$ with SD for F1=8, at the flow direction throughout of upstream to downstream of chute block

are constants varying with submergence level.



(a)



(b)

Fig. 6. Variation of C_p+C'_p with S_d for F_1=8, in XY-plane, (a): *Y=0* and (b): *Y=B/8*

power function as in y-direction towards the edge of chute block:

$$(C_p+C'_p)_m = K_1(x/d_1)^n \quad (7)$$

where K_1 and n are constants varying with submergence level.

Total pressure (C_p+C'_p) with F_1 for free

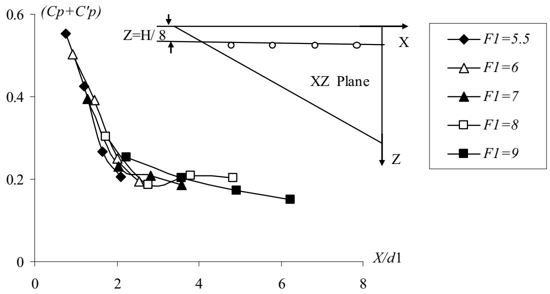


Fig.7. Variation of C_p+C'_p with F1 for Sd=0, at X direction in XZ-plane, at Z=H/8

hydraulic jump at side face (XZ Plane) both in X and Z directions are determined and depicted in (Fig. 7) and (Fig. 8) respectively. (Fig. 7) shows that (C_p+C'_p) falls in a decreasing trend with incoming flow condition, towards downstream and becomes steady as the F_1 values increase. On the other hand, (Fig.8) shows the variation of (C_p+C'_p) with F_1 where it increases from top face of chute block towards the channel bed and decreases as the F_1 values increase. The trend follows a polynomial function at low Froude number and falls in an increasing linear relationship as F_1 increases.

Variation of (C_p+C'_p) with S_d for Fr_1=8, at side face (XZ Plane) both in X and Z directions were observed and plotted in (Fig. 9) and (Fig. 10) respectively. The trend of variation is the same as is shown in (Figs. 7 and 8). It is evident from the diagrams that the increase in tailwater depth increases (C_p+C'_p) values.

(Fig.11) shows typical experimental probability densities of the pressure fluctuations for various Froude numbers and submergence ratios at different pressure holes. Analysis of all the results

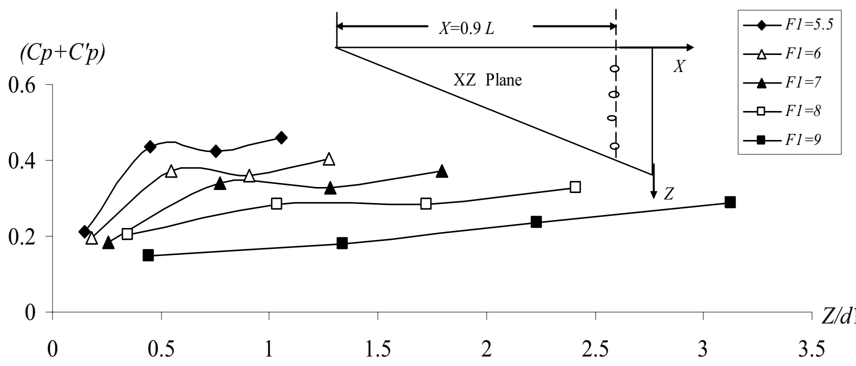


Fig. 8. Variation of C_p+C'_p with F1 for Sd=0, at Z direction in XZ-plane, at X=0.9L

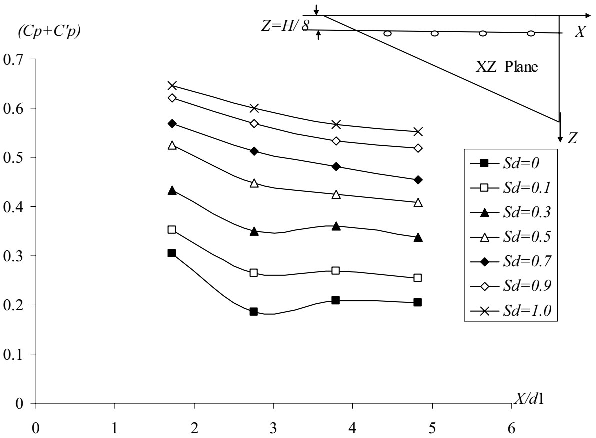


Fig. 9. Variation of C_p+C'_p with F_1 for S_d=*0*, at X direction in XZ-plane, at *Z=H/8*

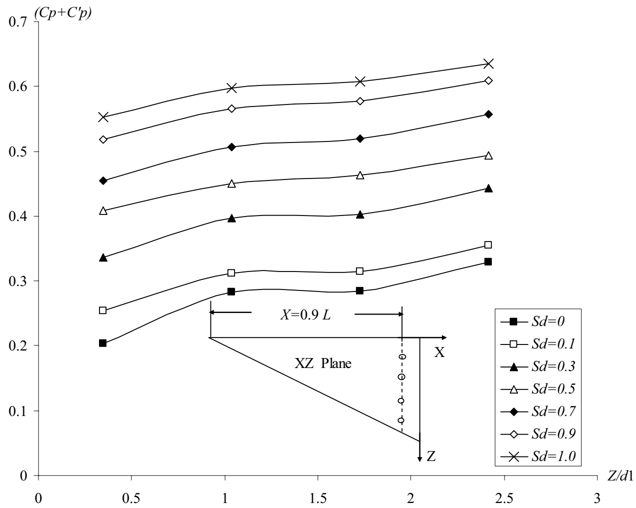


Fig. 10. Variation of C_p+C'_p with Sd for F_1=8, at *Z* direction in XZ-plane, at *X=0.9L*

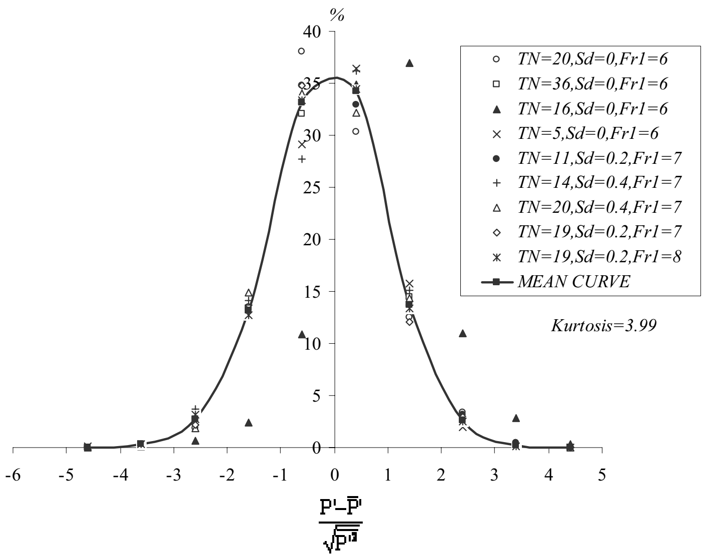


Fig. 11. Probability density distributions of pressure fluctuation

gathered in the present research shows that the peak instantaneous pressure fluctuations could be as large as ±4.5 times the RMS value, as depicted in (Fig. 11).

5. Conclusions

The total pressure field consisting mean and fluctuating components, were measured around a selected chute block in a SAF stilling basin. From the observations the following remarks would be concluded.

The magnitude of total pressure field at the face of spillway increasing towards of its toe independently from F_1 values.

The variation of $(C_p+C'_p)_m$ values with F_1 falls in a decaying power function whereas the position of $(C_p+C'_p)_m$ occurrence (X_m) with F_1 demonstrates a quadratic polynomial relationship.

The contribution of fluctuating pressure component to total pressure may vary between 0.44 to 2.11 times of mean pressure at downstream foot of chute blocks.

The variation of $(C_p+C'_p)$ with S_d at top face of the block in flow direction follows a polynomial trend. It is also indicated that the trend is tending to become almost decaying power function in y-direction towards the edge of chute block.

At side face the variation of $(C_p+C'_p)$ with incoming flow condition at flow direction,falls in a decreasing trend towards downstream and becomes steady as the F_1 values increase. Also as the S_d values increases the trend of total pressure variation tends to become flattered.

$(C_p+C'_p)$ values increase with F_1, from top face of chute block towards the channel bed and become flattered as F_1 values increase.

Statistical analysis showed that the peak instantaneous pressure fluctuations could be as large as ±4.5times the *RMS* value.

6. Notations

$A_1, A_2, A_3, A_4, B_1, C_1$ & K_1 = Constants

B, H & L = Width, height and length of experimental chute block respectively

C_p = Coefficient of mean pressure

C'_p = Coefficient of pressure fluctuation

$C_p+C'_p$ = Total pressure field

C'_{pm} = Maximum coefficient of pressure fluctuation

F_1 = Froude number of incoming flow to the stilling basin

L_B = Length of stilling basin

P = Mean hydrostatic pressure=ۥh

R = Reynolds number

RMS = Root Mean Square

S_d = Submergence ratio

T_w = Tailwater depth

X, Y, Z = Cartesian coordinates of each hole from origin O in Fig. 2.

x_m = X- coordinate of the pressure hole for maximum pressure fluctuation

d_1 & d_2 = Super-critical depth and sub-critical flow depth respectively

g = Gravitational acceleration

n = Constant

p'= Measured pressure fluctuation

= Mean pressure fluctuation

v = Mean flow velocity

v_1 = Mean flow velocity of incoming flow to the stilling basin

φ =Function of

ρ =Mass density of water

μ =Dynamic viscosity of water

ν =Kinematic viscosity

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