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JET STILLING BASIN

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A stilling basin is designed to dissipate the kinetic energy of the flow in a hydraulic jump. Sometimes an abrupt rise is introduced based on land topography and design requirements to increase the energy dissipation and to reduce the length of the jump. The main objective of the present study is to use the abrupt rise in a radial stilling basin at certain positions to create a jet flow. Experiments were conducted to investigate the effect of the relative position and relative depth of the rise on the characteristics of the jet. The results of experiments are compared with the free hydraulic jump in a radial basin of flat horizontal bed. The dimensional analysis was used to correlate the jet characteristics to the other relevant flow and rise parameters. Also Theoretical models are developed for the prediction of the relative depth and the relative energy loss of the jet. It is found that in comparison with the case of free jump in flat bed the values of the relative depth and relative energy loss are higher and the percentage of increase decrease with the increase of the rise position to the gate. It is found also that the values of relative length are lower comparing to the free jump and the percentage of decrease decreases with the increase of the rise position to the gate.

KEYWORDS: *Radial stilling Basin, Hydraulic jet, Energy dissipation and Abrupt rise.*

1. INTRODUCTION

Kinetic energy of water over large spillways must be dissipated in the stilling basin through generation of a jump in order to prevent severe scouring of waterway bed and failure of downstream structures as a result of the jump being swept out of the basin. To ensure the formation of a jump and to control its position under all probable operating conditions special structures (baffle blocks, sills, steps,…) are introduced in the basin. The jump in this case is called forced jump

According to studies of Khalifa and McCorquodale [11] and Abdel-Aal et al [1], it was found that the relative depth of free radial jump and the length of the jump were shorter than those formed in rectangular channels, while the rate of energy loss increases through the jump in radial basin compared to that in rectangular one. The effect of the sill on the jump characteristics depends on factors such as the sill configuration, sill location and sill spacing when more than one sill is used. Several investigations dealt with the effect of sill on the hydraulic jump characteristics when the sill is constructed beneath hydraulic jump such as Shukry [19], Rajaratnam [18], Ohtsu et al [16], and Hager and Li [9]. Hager and Li give one of these classifications of the forced hydraulic jump due to vertical sill. Wafaie [21, 22] investigated experimentally the free rectangular hydraulic jump phenomenon on roughened channel bed with dentated, solid, zigzagged bed sills, under different flow conditions, different bed sill heights, and different bed sill locations. Wilson [23] tested method for the control of jump location by jets to avoid the cavitation problems with the blocks and baffles under high heads. Manoochehr et al [12] studied the forced hydraulic jump in stilling basin with a continuous tall sill downstream a sluice gate.

NOTATIONS

B	width of the flume at the gate location (18 cm)	R_1	initial Reynolds number
b_{max}	width of the basin at max height of the jet	g	acceleration due to gravity
b_s	width of basin at the rise	H_u	upstream water depth over the bed
B	width of the flume at the end of the basin (30 cm)	Ls	distance between the initial position and the beginning of the rise
d_1	initial water depth of free hydraulic jump D.S. the gate	Lb	Radial basin length (130cm)
d_2	tail water depth	Le	length of the jet
d_{max}	maximum height of jet	Q	discharge passing through the flume
d_s	water depth above the rise	v_1	the average velocity of flow at the initial depth
E_1	The specific energy at the beginning of the jet	v_2	the average velocity at the end of the jet
E_2	The specific energy at the end of the jet	z	depth of abrupt rise
EL	The loss of energy	ρ	the density of water
F_1	Initial Froude number	μ	the dynamic viscosity of water

Other studies dealt with the effect of steps (abrupt rise or drop) on the hydraulic jump characteristics. Hager [6] performed experimental and theoretical investigations on B-type jumps at abrupt drops. Hager and Bretz [8] discussed the characteristics of A and B jumps at abrupt drops. The ranges of relative depth and length representative of these types of jump were analyzed with particular attention to the design of stilling basins. Ohatsu and Yasuda [15] presented a systematic investigation on the characteristics of the hydraulic jump over a wide range of negative steps. All the cases were studied theoretically by the use of momentum equation with measurements of the pressure distribution over the face of the step. Other studies on negative and positive steps in sloping rectangular channels include those of Husain et al. [10], Quraishi. and Al-Brahim [17] and Negm [13]. Armenio *et al* [3] investigated the pressure fluctuations beneath a hydraulic jump that developed over a negative step. The study was carried out experimentally using two different drops, an abrupt drop and a rounded one. A numerical simulation of minimum B-jumps in horizontal rectangular channels having an abrupt drop was given by Tokyay *et al* [20]. Before that, an A-type jump at a positive step was simulated numerically by Altan-Sakarya and Tokyay [2]. Few studies were conducted to discuss the effects of steps and end sill on the characteristics of the hydraulic jump in radial basins, Negm et al. [14] and Habib *et al* [4, 5].

The purpose of this study is to obtain a more efficient and economic stilling basin by creating a special case of the free jump in a radial stilling basin that called a jet which has a less length more energy loss and more height than the free jump. One way of creating a jet is by using an abrupt rise in the basin in a position close to the gate.

2. THEORETICAL APPROACH

2.1. Dimensional Analysis

Figure 1 shows a definition sketch for the jet in a radial stilling basin with abrupt rise. The following function can be formed:

$$f\,(\rho, g, \mu, d_1, d_2, dmax, V_1, z, Ls, Lb, Le) = 0 \quad \ldots\ldots\ldots (1)$$

in which ρ is the density of water, g is the gravitational acceleration, μ is the dynamic viscosity of water, d_1 is the initial depth of jump, d_2 is the tail water depth of jump, d_{max} is the apex height of the jet, V_1 is the average velocity of flow at the initial depth, z is the height of the abrupt rise, Ls is the distance between the initial position and the beginning of the rise, Lb is the length of the radial basin and Le is the length of jet.

Using the dimensional analysis principle based on the three repeating variables ρ, d_1 and V_1, Eqn. (1) becomes

$$f\left(\frac{Le}{d_1}, \frac{d_{max}}{d_1}, \frac{d_2}{d_1}, \frac{z}{d_1}, \frac{Lb}{d_1}, \frac{Ls}{d_1}, R_1, F_1\right) = 0.0 \quad \ldots\ldots\ldots (2)$$

Where R_1 and F_1 are respectively the Reynolds and Froude numbers just downstream the gate. In Eqn. (2):

- Both d_2/d_1 and d_{max}/d_1 are function of F_1.
- The effect of R_1 is neglected as the viscosity has a negligible effect on the hydraulic jump characteristics in the present study because the temperature was fixed during the experimental work.
- Dividing Ls/d_1 by Lb/d_1. Equation (2) becomes:

$$\frac{Le}{d_1} = f\left(\frac{z}{d_1}, \frac{Ls}{Lb}, F_1\right) \quad \ldots\ldots\ldots (3)$$

Similar relationships for the depth ratio ($dmax/d_1$) and for the energy loss ratio (EL/E_1) could be obtained as follow.

$$\frac{dmax}{d_1} = f\left(\frac{z}{d_1}, \frac{Ls}{Lb}, F_1\right) \quad \ldots\ldots\ldots (4)$$

$$\frac{EL}{E_1} = f\left(\frac{z}{d_1}, \frac{Ls}{Lb}, F_1\right) \quad \ldots\ldots\ldots (5)$$

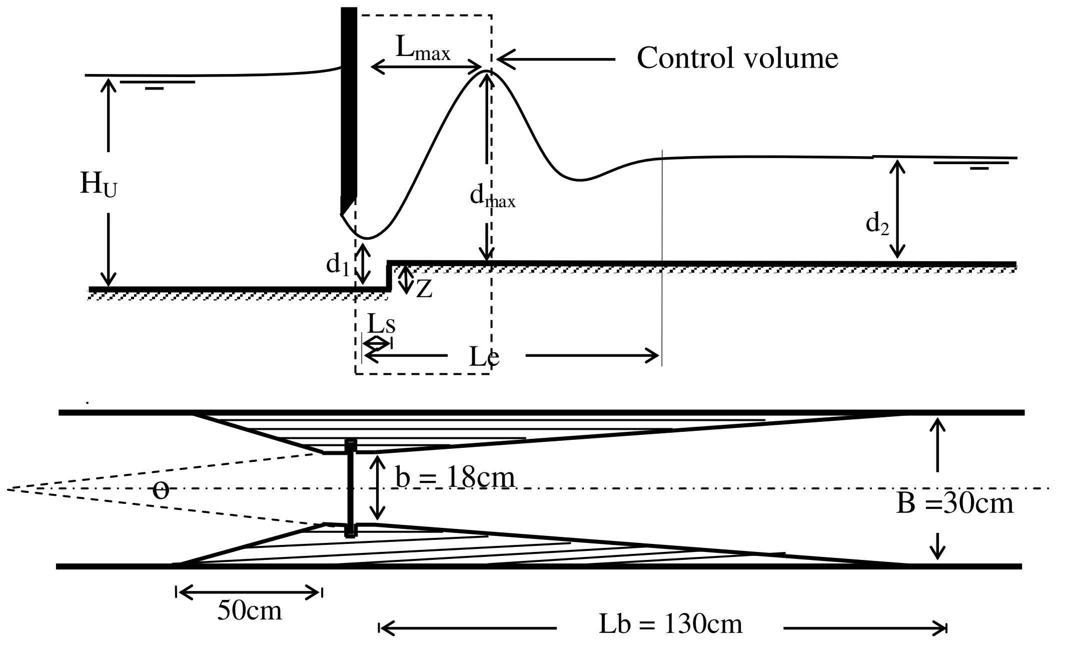

Fig. (1) Definition sketch

2.2 The relative depth of jet (D_{max})

Both the 1-D momentum and continuity equations are used to develop a theoretical design model for computing the depth ratio ($dmax/d_1$) for the jet formed in radial stilling basin provided with an abrupt rise. The present development is based on the following assumptions: (a) the flow is radial and steady (b) the liquid is incompressible (c) the channel is horizontal and has smooth boundaries, (d) hydrostatic pressure distribution at the beginning of the jet, at the maximum height and at the rise. (e) uniform velocity distribution (f) the effects of air entrainment and turbulence are neglected.

The control volume where the momentum equation is applied starts from the section 1 just down stream the gate to the maximum height of the jet Figure (1).
The momentum equation written as follows:

$$P_{max} + P_{rise} - 2\,P_s \sin(\theta/2) - P_1 = \frac{\gamma Q}{g}(V_1 - V_{max}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

in which P_1 is the hydrostatic pressure at the beginning of the jet, P_{max} is the hydrostatic pressure at max. height of the jet, P_{rise} is hydrostatic pressure due to the abrupt rise and PS is channel side pressure from the initial water depth to the max. height of the jet. These forces may be expressed as follows:

$$P_1 = \frac{\gamma d_1^2 b_1}{2}, \quad P_2 = \frac{\gamma d_{max}^2\, b_{max}}{2}, \quad P_{rise} = \frac{1}{2} z\gamma(2d_s + z)\, b_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

And P_s =

$$\frac{\gamma}{2}\left[L_s\,(d_1^2+d_s^2+z^2+2d_s z)+(L_{max}-L_s)(d_s^2+d_{max}^2)\right]\ldots\ldots(8)$$

Applying the continuity equation:

$Q = v_1 b_1 d_1 = v_{max}\, b_{max} d_{max}$

Where v_{max} is the velocity at max height, b_{max} is the basin width at max height $= b_1 + 2\, L_{max}\, \sin(\theta/2)$

$$\text{Then } v_{max} = \frac{v_1 b_1 d_1}{d_{max}\, b\max} = \frac{v_1 e}{\frac{d_{max}}{d_1}\left(\frac{b_{max}}{B}\right)} \quad \ldots\ldots \quad (9)$$

Substituting from equations (7) to (9) in equation (6), one obtains

$$F_1 = \left[\frac{\left[D_{max}^2\,(e+2C^*)+e\,(Z^2+2ZD-1)-2(C^*+CD^2)\right]}{2e\,\left(1-\frac{e}{D_{max}\,(e+2C)}\right)}\right]^{1/2} \quad \ldots\ldots(10)$$

Where

$$D_{max} = \frac{d_{max}}{d_1},\ Z = \frac{z}{d_1},\ D = \frac{d_s}{d_1},\ C = \frac{L_{max}}{B}\sin\frac{\theta}{2},\ C^* = \frac{L_s}{B}\sin\frac{\theta}{2},\ e = \frac{b_1}{B} \text{ and } F_1 = \frac{v_1}{\sqrt{g d_1}}$$

Equation (8) tends to the previously developed equation by Hager [7] that describing the relation between the inflow Froude number (F_1) and the relative depth ratio (D_o) for hydraulic jump formed in channel transitions with linearly varying channel width and horizontal channel bottom. When the effect of the rise is neglected i.e. z = 0.0 that leads to:

$$Z = 0.0,\ D_{max} = D = D_o \text{ and } C = C^* = (1-e)/2.$$

2.3. Energy Approach

Applying the energy equation at sections 1 and 2 where the jet begins and ends. And assuming uniform velocity distribution and hydrostatic pressure distribution, the following equation can be obtained:

$$EL/E_1 = (E_1 - E_2)/E_1 = 1 - (E_2/E_1) = 1 - \frac{z + d_2 + v_2^2/2g}{d_1 + v_1^2/2g} \quad \ldots\ldots(11)$$

Where E_1, E_2 is the specific energy at the beginning and the end of the jet, EL is the loss of energy, EL/E_1 is the relative energy loss and v_2 is the average velocity at the end of the jet.

From the continuity equation one can obtain the following equation:

$$V_2 = \frac{v_1\, e}{D_o\,(e+2C^{**})} \quad \ldots\ldots(12)$$

Where $C^{**} = \frac{L_e}{B} \sin \frac{\theta}{2}$ and $D_o = d_2/d_1$

By substituting in equation (9) the following explicit form can be obtained:

$$\frac{EL}{E_1} = 1 - \left[\frac{D_o^2 (Z + D_o)(e + 2C^{**})^2 + 0.5 e F_1^2}{D_o^2 (1 + 0.5 F_1^2)(e + 2C^{**})^2} \right] \qquad (13)$$

3. EXPERIMENTAL WORK

The experimental work of this study was conducted using a re-circulating adjustable flume of 15.0 m long, 45 cm deep and 30 cm wide. The discharges were measured using pre-calibrated orifice meter fixed in the feeding pipeline. The tailgate fixed at the end of the flume was used to control the tail-water depth of flow. The radial basin was made from a clear prespex to enable visual inspection of the phenomenon being under investigation. The model length was kept constant at 130 cm and the angle of the divergence was kept constant to 5.28^o. The model was fixed in the middle third of the flume between its two side-walls as shown in Figure 1. A smooth block of wood was formed to fit well inside the basin model extending from the position where the rise was desired downstream the sluice gate to the tailgate. The wood was painted very well by a waterproof material (plastic) to prevent wood from changing its volume by absorbing water. A fixed height of the step of 2.5 cm was used at two different positions of the step (Ls/Lb = 0.0, 0.25) downstream from the gate opening were tested under almost the same flow conditions. Experimental data were as follows: Froude numbers (3.0 -7.0), relative position of the rise, (Ls/Lb = 0.0, 0.25), and relative height of the step, z/d_1 (0.0 – 1.9).

Each model was tested using five different gate openings and five discharges for each gate opening. The measurements were recorded for each discharge. A typical test procedure consisted of (a) A gate opening was fixed and a selected discharge was allowed to pass. (b) The tailgate was adjusted until a jet is formed just downstream the gate. (c) Once the stability conditions were reached, the flow rate, length of the jet, water depths upstream and at the vena contracta downstream of the gate, the maximum depth of the jet the tail water depth, in addition to the surface profile. The length of jet was taken to be the section at which the flow depth becomes almost level. These steps were repeated for different discharges and different gate openings and so on till the required ranges of the parameters being under investigation were covered.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The hydraulic jump occurs when the supercritical stream of high velocity meats a subcritical stream of sufficient depth and lower velocity. In this study the supercritical flow through the gate opening collides with the face of the close abrupt rise to the gate, which changes the velocity direction forcing the flow up to form the jet. The experimental results of the present investigation will be analyzed in this part in comparison with free hydraulic jump formed in a radial stilling basin at a horizontal flat bed (without rise) to obtain the characteristics of the jet stilling basin.

4.1. The relative depth of the jet (d_{max}/d_1)

Figure (2) a and b shows the relation between the initial Froude number F_1 and the relative depth of the jet d_{max}/d_1 for various relative depth of the rise z/d_1 at the two rise positions (Ls/Lb = 0.0, 0.25) respectively. The figure includes also the same relation for the free jump in flat bed. It shows that the relative depth increases with the increase of F_1 and with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of d_{max}/d_1 are higher, especially for the first position. The percentages of increase in relative depth are presented in Table (1).

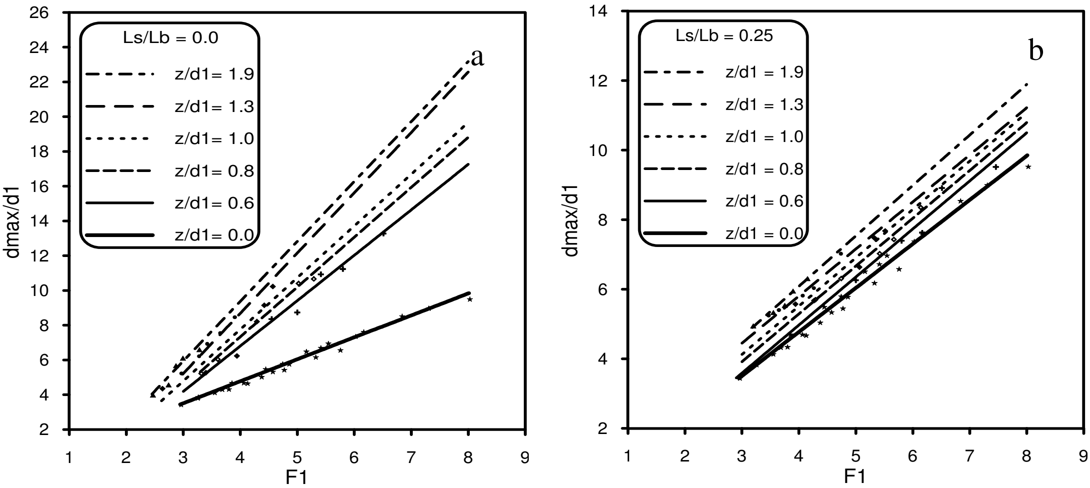

Fig. (2) Relation between F_1 and d_{max}/d_1 for different z/d_1

Table (1) percentages of increase and decrease of jet characteristics

z/d1	%age increase in relative depth		%age decrease in relative length		%age increase in relative energy loss	
	Ls/Lb = 0.0	Ls/Lb = 0.25	Ls/Lb = 0.0	Ls/Lb = 0.25	Ls/Lb = 0.0	Ls/Lb = 0.25
1.9	96.65	29.44	48.24	26.50	32.15	15.25
1.3	82.13	22.53	36.99	22.89	24.69	10.45
1.0	62.72	16.84	31.20	19.17	16.70	7.13
0.8	53.66	12.02	26.51	14.31	10.51	4.85
0.6	42.57	5.36	22.39	9.26	4.00	3.15

4.2. The relative length of the jet (Le/d_1)

Figure (3) a and b shows the relation between the initial Froude number F_1 and the relative length of the jet Le/d_1 for various relative depth of the rise z/d_1 at the two rise positions (Ls/Lb = 0.0, 0.25) respectively. The figure includes also the same relation for the free jump in flat bed. It shows that the relative length increases with the increase of F_1 and decreases with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of Le/d_1 are lower, especially for the first position. The percentages of decrease in relative length are presented in Table (1).

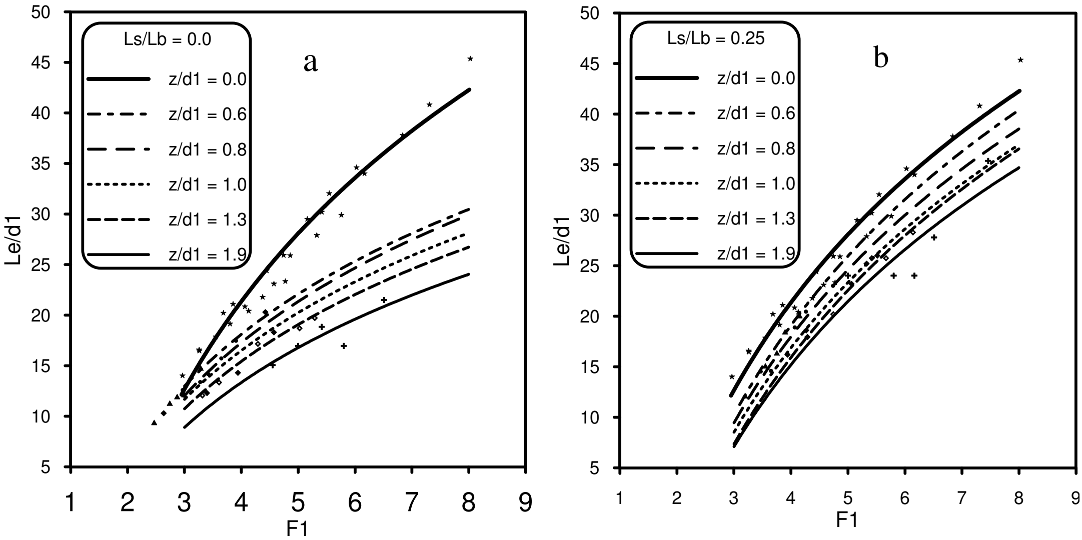

Fig. (3) Relation between F_1 and Le/d_1 for different z/d_1

4.3. The relative energy loss of the jet (EL/E_1)

Figure (4) a and b shows the relation between the initial Froude number F_1 and the relative energy loss of the jet EL/E_1 for various relative depth of the rise z/d_1 at the two rise positions (Ls/Lb = 0.0, 0.25) respectively. It shows that the relative Energy loss increases with the increase of F_1 and with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of EL/E_1 are higher, especially for the first position. The percentages of increase in relative energy loss are presented in Table (1).

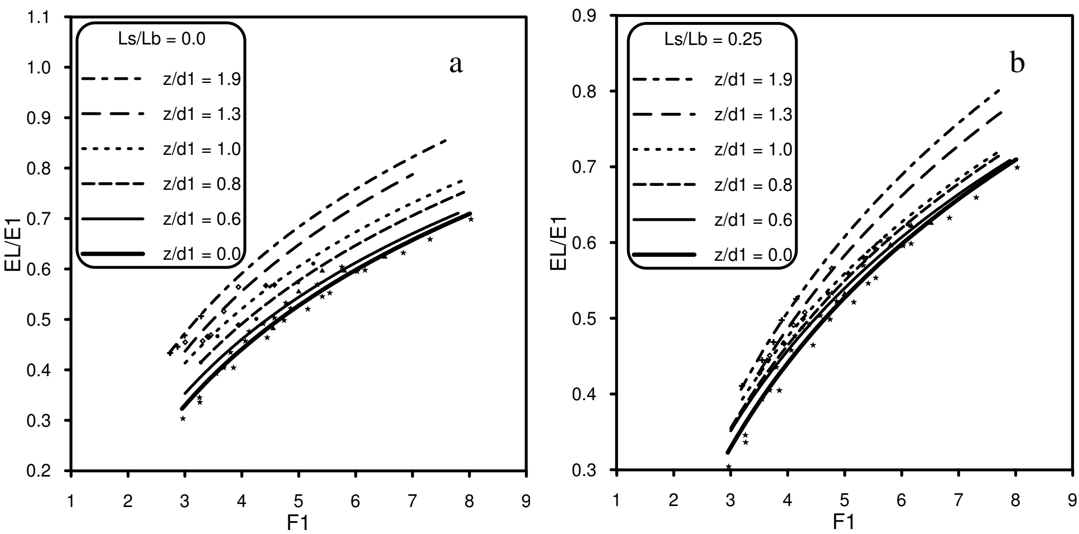

Fig. (4) Relation between F_1 and EL/E_1 for different z/d_1

4.4. The dimensionless surface profile

Figures (5 to 9) show the dimensionless surface profile of the jet for the two tested positions and the free jump of the flat bed case for the same Froude numbers (6.5, 5.3, 4.6, 4.0 and 3.2) respectively. The figures showed that the same previous results and clearly showed that as the rise closes to the gate opening as the walls of the stilling basin be higher in height and shorter in length with higher energy loss.

The percentages of increase and decrease of the jet characteristics in Table (1) are represented graphically in figures 10, 11 and 12 to show the effect of the relative position of bed rise on jet characteristics. These figures show that the position of Ls/Lb = 0.0 give the higher values of relative depth and relative energy loss and lower values of relative length of the jump.

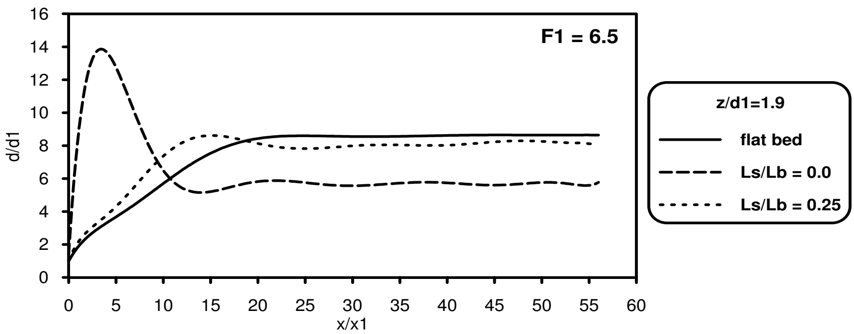

Fig. (5) Dimensionless surface water profiles for the $F_1 = 6.5$

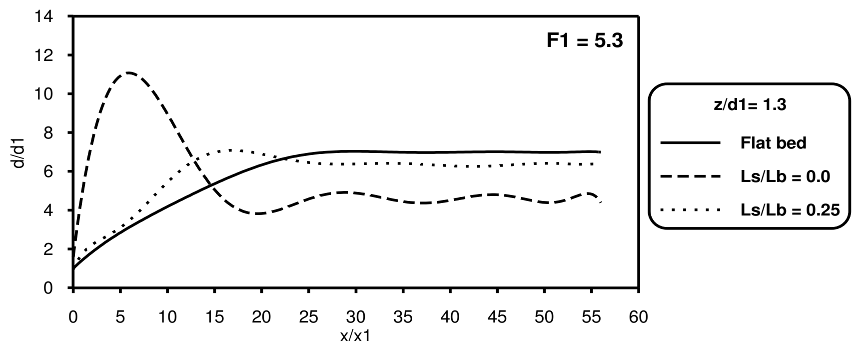

Fig. (6) Dimensionless surface water profiles for the $F_1 = 5.3$

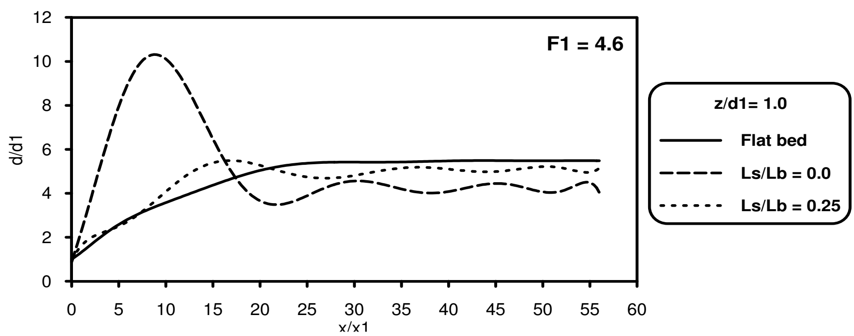

Fig. (7) Dimensionless surface water profiles for the $F_1 = 4.6$

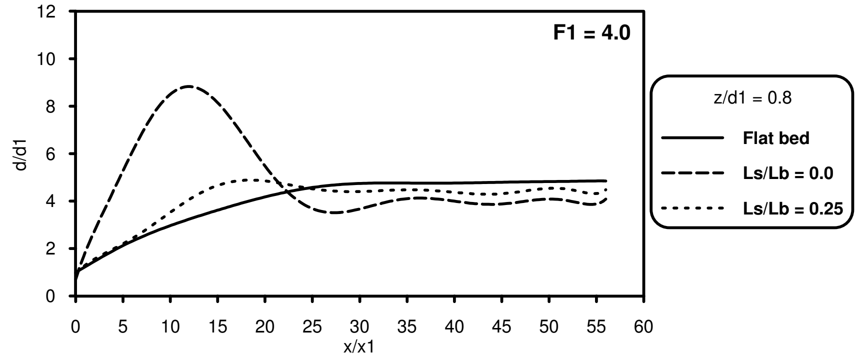

Fig. (8) Dimensionless surface water profiles for the $F_1 = 4.0$

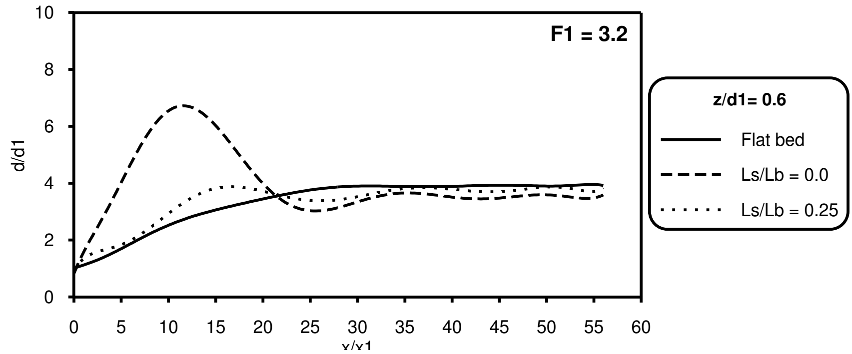

Fig. (9) Dimensionless surface water profiles for the $F_1 = 3.2$

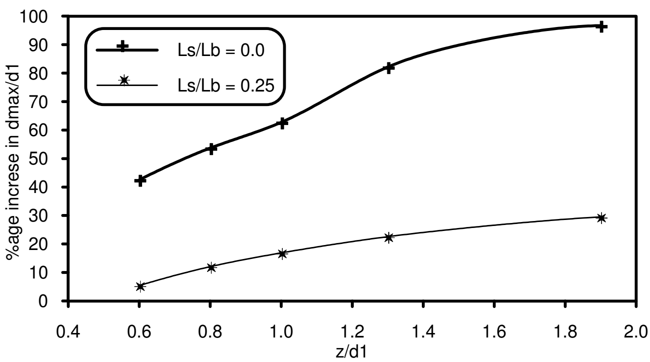

Fig.(10) Relation between % ages of increase in $d_{max}/d_1$and z/d_1

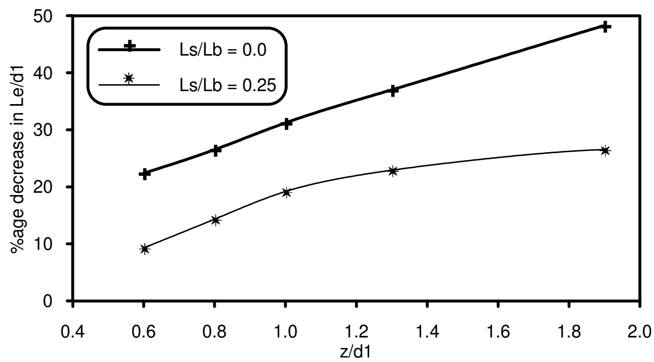

Fig.(11) Relation between % ages of decrease in $Le/d_1$and z/d_1

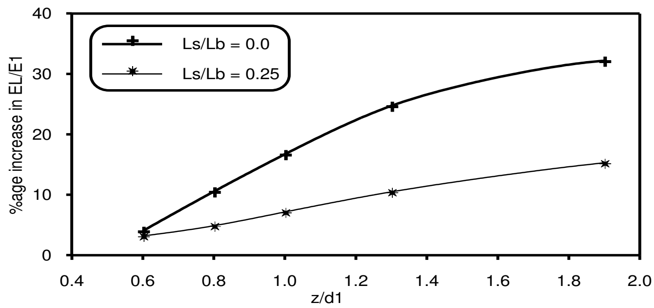

Fig. (12) Relation between % ages of increase in EL/E_1 and z/d_1

5. VERIFICATION OF THE DEVELOPED MODELS

Figure (13) presents the comparison between theoretical values of Froude number (F_1 The) as computed from equation (10) and its values as computed from the measurements (F_1 Exp) of the jet formed in a radial basin with abrupt rise closed to the gate. The coefficient of determination (R- squared) between theoretical and measured values of Froude number is 0.826 and between the residuals and the theoretical values is 0.0499 indicating good agreement between theoretical and measured values.

Figure (14) presents the comparison between theoretical values of relative energy loss EL/E_1 as computed from equation (13) and its experimental values as computed from the measurements. The coefficient of determination (R- squared) between theoretical and measured values is 0.99 and between the residuals and the theoretical values is 0.4. Inspection of this figure indicates that good agreements between theoretical and measured values are achieved.

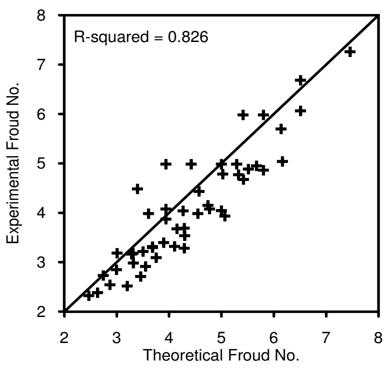

Fig. (13) Results of the theoretical model of relative depth of the jet (Equ. 10)

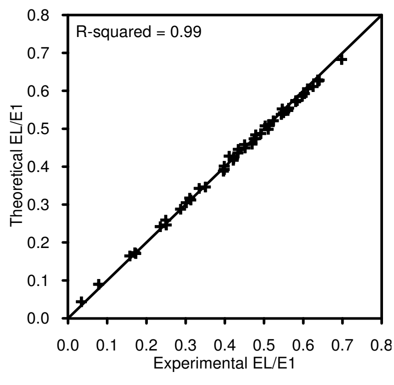

Fig. (14) Results of the theoretical model of relative energy loss (Equ. 13)

6. CONCLUSIONS

An experimental investigation is conducted in a laboratory flume using abrupt rise at two different positions close to the gate to create a jet of flow in a radial stilling basin. The experimental data is analyzing using the principles of dimensional analysis. Also

Theoretical models, equations (10) and (13) are developed for the prediction of the relative depth and the relative energy loss of the jet that could be formed in radial stilling basins when abrupt rise is existed in the basin in a position closed to the gate. The characteristics of the jet compared with that of the free hydraulic jump formed in a radial stilling basin at a horizontal flat bed (without rise) to obtain the characteristics of the jet stilling basin. The results of the analysis indicated that:

- The relative depth of the jet increases with the increase of F_1 and with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of d_{max}/d_1 are higher, especially for the first position Ls/Lb = 0.0 for the tested ranges of Froude number and relative depth of rise.
- The relative length increases with the increase of F_1 and decreases with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of Le/d_1 are lower, especially for the first position.
- The relative Energy loss increases with the increase of F_1 and with the increase of the relative depth of the rise z/d_1. In comparison with the case of free jump in flat bed the values of EL/E_1 are higher, especially for the first position.
- As the rise closes to the gate opening as the walls of the stilling basin be higher in height and shorter in length with higher energy loss comparing to the free jump.
- The average percentage of increase in the relative depth of the jet is about 63% for Ls/Lb = 0.0 and about 15% for Ls/Lb = 0.25 for the unit of z/d_1.
- The average percentage of decrease in the relative length of the jet is about 31% for Ls/Lb = 0.0 and about 17% for Ls/Lb = 0.25 for the unit of z/d_1.
- The average percentage of increase in the relative energy loss of the jet is about 15% for Ls/Lb = 0.0 and about 8% for Ls/Lb = 0.25 for the unit of z/d_1.
- The first position of the rise is more efficient with respect to the relative length and energy loss
- The developed theoretical models showed good agreement with the measured values for both relative depth and energy loss of the jet.

Finally a jet stilling basin can be designed instead of the jump stilling basin with more energy loss, less relative length and more relative height by using an abrupt rise very close to the gate.

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Appendix A

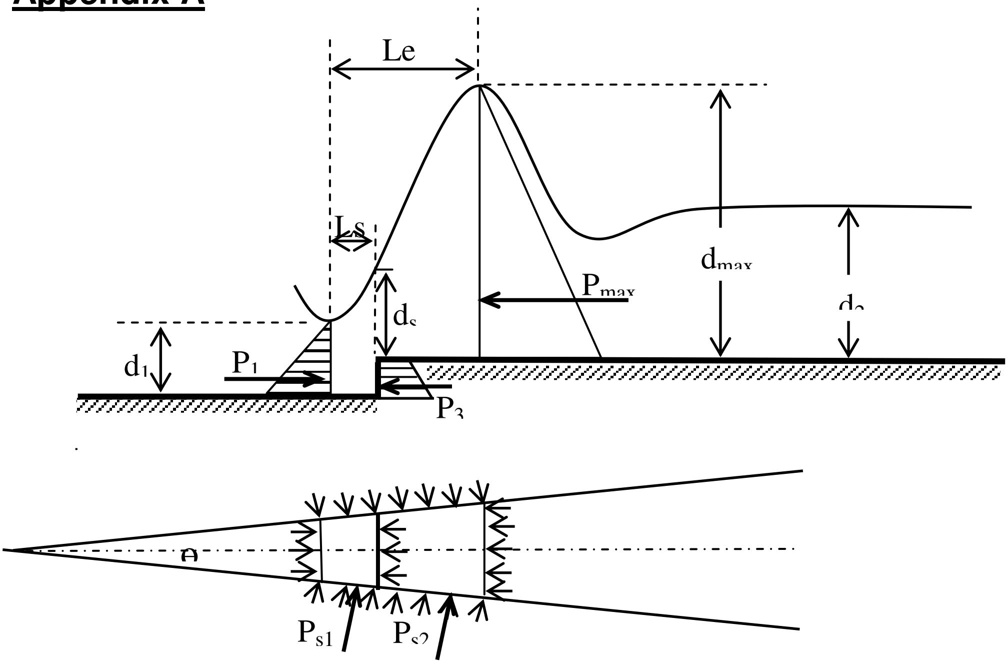

Fig. (15) definition sketch showing the pressure distributions

-The formula of the side pressure

$$P_{s1} = \frac{\gamma}{2}\left[Ls\,(d_1^2 + d_s^2 + z^2 + 2d_s z)\right]$$

$$P_{s2} = \frac{\gamma}{2}\left[(Le - Ls)\,(d_s^2 + d_{max}^2)\right]$$

$$Ps = P_{s1} + P_{s2} = \frac{\gamma}{2}\left[Ls\,(d_1^2 + d_s^2 + z^2 + 2d_s z) + (Le - Ls)\,(d_s^2 + d_{max}^2\right]$$

$$2Ps\ \sin(\theta/2) = 2\ (\frac{b_{max} - b_1}{2L_{max}})\ \frac{\gamma}{2}\left[Ls\,(d_1^2 + d_s^2 + z^2 + 2d_s z) + (Le - Ls)\,(d_s^2 + d_{max}^2\right]$$

-The formula of the abrupt rise pressure

$$P_{rise} = \frac{1}{2} z\gamma [d_s + (d_s + z)] b_s = \frac{1}{2} z\gamma (2 d_s + z) b_s$$

-The formula of V_{max}

from the continuity equation:
$Q = v_1 b_1 d_1 = v_{max}\, b_{max} d_{max}$

Where v_{max} is the velocity at max height, b_{max} is the basin width at max height $= b_1 + 2\, L_{max} \sin(\theta/2)$

Then $V_{max} = \dfrac{v_1 b_1 d_1}{d_{max} b_{max}}$ multiplying V_{max} by B/B

Then $V_{max} = \dfrac{v_1 e}{\dfrac{d_{max}}{d_1}(\dfrac{b_{max}}{B})}$ where $e = b_1/B$

Sub. For bmax in vmax equation

Then $V_{max} = \dfrac{v_1 e}{\dfrac{d_{max}}{d_1}(e + 2C)}$, Where $C = \dfrac{L_{max}}{B} \sin \dfrac{\theta}{2}$

Substituting in equation (6) for P_1, P_{max}, 2Ps $\sin(\theta/2)$, P_{rise} and V_{max} with simplifying leads to

$$F_1 = \left[\frac{\left[D_{max}^2 (e + 2C^*) + e\ (Z^2 + 2ZD - 1) - 2(C^* + CD^2) \right]}{2e\ (1 - \dfrac{e}{D_{max}\ (e + 2C)})} \right]^{1/2} \quad \text{Equ. (10)}$$

Where $D_{max} = \dfrac{d_{max}}{d_1}$, $Z = \dfrac{z}{d_1}$, $D = \dfrac{d_s}{d_1}$, $C^* = \dfrac{L_s}{B} \sin \dfrac{\theta}{2}$, $e = \dfrac{b_1}{B}$ and $F_1 = \dfrac{v_1}{\sqrt{gd_1}}$

-The formula of the relative energy loss EL/E_1

Applying the energy equation at sections 1 and 2 where the jet begins and ends.

$E_1 = z + d_2 + v_2^2/2g$ and $E_2 = d_1 + v_1^2/2g$

$$EL/E_1 = 1 - (E_2/E_1) = 1 - \frac{z + d_2 + v_2^2/2g}{d_1 + v_1^2/2g}$$

The average velocity at the end of the jet $V_2 = \dfrac{v_1\, e}{D_o\, (e + 2C^{**})}$

Where $C^{**} = \dfrac{L_e}{B} \sin \dfrac{\theta}{2}$ and $D_o = d_2/d_1$

Then $$\frac{EL}{E_1} = 1 - \frac{z + d_2 + \dfrac{V_1^2 e^2}{D_o^2 (e + 2C^{**})^2\, 2g}}{d_1 + V_1^2/2g}$$ multiplying EL/E_1 by d_1/d_1

$$\frac{EL}{E_1} = 1 - \frac{Z + D_o + \dfrac{F_1^2 e^2}{2D_o^2 (e + 2C^{**})^2}}{(1 + 0.5F_1^2)}$$ multiplying EL/E_1 by $\dfrac{2D_o^2 (e + 2C^{**})^2}{2D_o^2 (e + 2C^{**})^2}$

$$\frac{EL}{E_1} = 1 - \left[\frac{D_o^2 (Z + D_o)(e + 2C^{**})^2 + 0.5\, e\, F_1^2}{D_o^2 (1 + 0.5F_1^2)(e + 2C^{**})^2}\right] \quad \text{Equ. (13)}$$

أحواض تهدئة للسريان المندفع لأعلى

منشآت التحكم على شبكات الري و الصرف يتم تزويدها في الخلف بأحواض تهدئة تعمل على احتواء القفزات الهيدروليكية المتكونة و تبديد الطاقة الهائلة خلف المنشآت و ذلك لحماية المنشآت من النحر خلف الفرشة أو بالحد من حدوثه. و عند تصميم المنشآت يلجأ المهندسون إلى إحداث ارتفاع مفاجئ بسبب تضاريس الأرض أو لمتطلبات التصميم وذلك لزيادة تبديد الطاقة و الحد من طول القفزة. والهدف الرئيسي من هذه الدراسة هو استخدام الارتفاع المفاجئ في حوض التهدئة المتسع تدريجيا (القطري) لخلق سريان مندفع لأعلى بهدف إحداث المزيد من التشتت للطاقة و تقليل طول الحوض. وقد أجريت العديد من التجارب المعملية لمعرفة مدى تأثير الموقع النسبي من بوابة التحكم في السريان وكذلك العمق النسبي للارتفاع المفاجئ على خصائص السريان. كما تم عمل دراسة نظرية. اشتملت هذه الدراسة على عمل تحليل بعدي لإيجاد علاقة بين الخصائص الأساسية للسريان المندفع لأعلى بالمتغيرات التي تؤثر على تلك الخصائص وكذلك بالمتغيرات الخاصة بالإرتفاع المفاجئ في القاع. كذلك فقد تم استخدام معادلتي كمية الحركة و الاستمرارية لاستنباط معادلة نظرية للعمق النسبي للسريان المندفع و كذلك استخدام نظرية بقاء الطاقة لحساب الطاقة النسبية المفقودة. وأظهرت النماذج النظرية المستنبطة توافق جيد مع القيم المقاسة لكل من العمق النسبي و الطاقة المفقودة للسريان وقد تم مقارنة نتائج التجارب مع القفزة الهيدروليكية الحرة المتولدة في حوض تهدئة قطري ذو قاع مسطح. حيث تبين أن قيم العمق النسبي و الطاقة النسبية المفقودة للسريان المندفع أعلى ونسبة الزيادة تقل مع زيادة البعد النسبي للإرتفاع المفاجئ. بينما يقل الطول النسبي مقارنة بطول القفزة الحرة ونسبة النقص تقل مع زيادة بعد الإرتفاع المفاجئ عن البوابة. وبذلك يمكن تصميم حوض تهدئة بطول اقل مع فقدان المزيد من الطاقة بإنشاء ارتفاع مفاجئ على مسافة قريبة جدا من البوابة.