EFFECT OF BAFFLE BLOCKS ON THE PERFORMANCE OF RADIAL HYDRAULIC JUMP

O. S. Rageh

Irrigation & Hydraulics Dept., Faculty of Engineering
El-Mansoura University, El-Mansoura, Egypt

ABSTRACT

The effect of baffle block (sill) on a radial hydraulic jump (R.H.J.) has been investigated and analyzed, in order to derive the limiting design parameters for this type of jump in expanding channels. The limiting design conditions refer to the radial hydraulic jump, when it occurs entirely on the horizontal bed, with a sill liable to move in both horizontal and vertical directions. This study was carried out in the laboratory for Froude number ranged from 2 to 6.5 to find non-dimensional relationships between the design parameters of radial hydraulic jump for different height of local baffle blocks. Generally the obtained results showed a good fitting between the different' parameters. Also results indicated that the energy loss and the sequent depth for a radial hydraulic jump are affected by baffle blocks.

INTRODUCTION

Hydraulic jump is one of the classical problems in the field of applied hydraulics. It was first investigated experimentally by Bidonein in 1818. This led Belanger in 1828 to distinguish between mild (subcritical) and steep (supercritical) slopes. Hydraulic jump is frequently produced by barrier in originally uniform flow. There after abundant studies were made and the results were quoted by many writers. Although most hydraulic jumps in stilling basins are rectangular in plan, there are several stilling basins that have diverging sidewalls.

The term radial hydraulic jump refers to a jump in a stilling basin with diverging walls, i.e. radially expanding flow. The radial hydraulic jump can be controlled or affected by sills of various designs, such as sharp-crested weir, broad crested weir, and abrupt rise and drop in channel floor. The function of the sill is to ensure the formation of a jump and to control its position under all probable operating conditions.

The energy loss in the radial hydraulic jump is slightly higher than the corresponding one in rectangular jump. In practice, the stilling basin is seldom designed to confine the entire length of a free hydraulic jump on the paved apron, because such a basin would be too expensive. Consequently, accessories to control the jump are usually installed in the basin. Baffles and sills are used simply as safety devices and the basin is designed to have the full, free jump sequent depth [7,8]. There are other designs for a reduced sequent depth in rectangular jump by assuming that appurtenances to dissipate a portion of the excess energy [1,6].

A few studies of diverging flow basins with baffle blocks have been reported in the literature. Moore and Meshgin in 1970 studied the use of the radial hydraulic Jump as an energy dissipator for culvert outlets, the Froude numbers in their experiments were relatively low ($F_r < 3$) while their flare angles were large ($20<\theta<60$). Nettleton and McCorquodale [9] studied the effect of baffle blocks on the performance of the radial hydraulic jump. His results indicated that an end sill would improve the performance of the radial stilling basin. Therefore, in this study an attempt is made to explore design parameters for radial hydraulic jump on a horizontal slope with affecting baffle blocks.

Analytical study

The analytical study is developed based on in two ways; (l) dimensional analysis and (2) the momentum approach in the direction of flow.

(1) Dimensional analysis:

The followings are the parameters considered for the dimensional analysis which are defined in Figure (1). Of the 13 quantities considered, equation (1) could be obtained:

$$L_j = \phi\,(h_g, y_1, y_2, q, h, r_1, r_2, \mu, \rho, g, x, \theta) \quad \text{.........................} \; (1)$$

These variables are, the initial water depth y_1; sequent water depth, downstream sill y_2; length of jump L_j; gate opening h_g; height of baffle block h; distance of baffle block from the gate x; discharge per unit width of flume q; acceleration due to gravity g; radius of the beginning of jump started from an imaginary center r_1; radius of the end of jump started from an imaginary center r_2; mass density of fluid ρ; dynamic viscosity μ; and total angle of divergence θ.

By using Buckingham pi-theorem, the three repeating variables, such as ρ, θ, and y_1 are chosen as important variables, and the following dimensionless relationship is obtained as:

$$L_j/y_1 = \phi\,(h_g/y_1, y_2/y_1, h/y_1, \mu/\rho q, g y_1/q, x/y_1, r_1 \operatorname{Sin}\theta/y_1, r_2 \operatorname{Sin}\theta/y_2) \quad \text{...} \; (2)$$

which may be rewritten as:

$$L_j/y_1 = \phi\,(h_g/y_1, y_2/y_1, h/y_1, R_n, F_r, x/h, r_2/r_1) \quad \text{..............................} \; (3)$$

In which; R_n = Reynolds number, which can be neglected because the viscous force, is not significant with respect to gravitational force. Since the ratio of y_2/y_1 is a function of F_r, and h_g/y_1 is a value round 1.5, are also omitted. Then, the dimensional analysis in equation (3) can be expressed in its final form as:

$$L_j/y_1 = \phi\,(F_r,\ x/h,\ r_2/r_1) \qquad (4)$$

(2) *Momentum approach:*

The momentum analyses have been adopted to obtain a suitable radial hydraulic jump equation [5,2].

By applying the momentum equation to the element shown in Figure (1) with considering the following assumptions, liquid is incompressible, flow is radial and steady, frictional sheer along the boundaries is negligible, kinetic energy correction factors α_1 and α_2 are unity; momentum coefficients β_1 and β_2 are also unity; channel is horizontal; and water depth does not depend on θ. With these assumptions the momentum equation leads to [3]:

$$P_1 + 2P_s \operatorname{Sin}(\theta/2) - P_2 = \rho Q(V_2 - V_1) \qquad (5)$$

In which P_1, P_2 are hydrostatic forces at sections 1 and 2 respectively in the radial direction respectively and P_s is the side pressure force, which are:

$$P_1 = \gamma y_1^2 r_1 (\sin\theta/2) \qquad (6a)$$

$$P_2 = \gamma y_2^2 r_2 (\sin\theta/2) \qquad (6b)$$

$$P_s = \int_{r_1}^{r_2} (\gamma y^2/2).dr \qquad (7)$$

Velocities V_1 and V_2 are in section 1 and 2, respectively and equal to:

$$V_1 = Q/(2r_1y_1\,(\sin\theta/2)) \qquad (8a)$$

$$V_2 = Q/(2r_2y_2\,(\sin\theta/2)) \qquad (8b)$$

The effective surface profile is given by:

$$(y - y_1)/(y_2 - y_1) = (r - r_1)/(r_2 - r_1) \qquad (9)$$

by substituting equation (9) into equation (7), the side pressure, P_s, can be written as:

$$P_s = (\gamma(r_2 - r_1)/6)(y_1^2 + y_1y_2 + y_2^2) \qquad (10)$$

Substitution all items in the above equations into equation (5), the general R.H.J. equation could be obtained as:

$$y_o^3 - ((r_o-1)/(2r_o+1))y_o^2 - ((r_o+2+6F_r^2)/(2r_o+1))y_o+((6F_r^2)/(r_o(2r_o+1)) = 0 \quad \text{......................} (11)$$

in which:

$r_o = r_2/r_1$; the sequent radius ratio,

$y_o = y_2/y_1$, the sequent depth ratio, and

$F_r = V_1/(gy_1)^{0.5}$, the upstream Froude number

This equation involves three parameters, namely r_o, y_o and F_r.

The energy loss in radial hydraulic jump can be obtained by applying the energy and continuity equations between sections 1 and 2, Fig. (1), as:

$$\Delta E/E_1 = 1 - ((F_r+2r_oy_o)/(r_oy_o(F_r+2))) \quad \text{.................................} (12)$$

EXPERIMENTAL STUDY

The tests were carried out in the Hydraulic Laboratory, Faculty of Engineering, Mansoura University, in 6m long fixed-bed flume. The flume has a rectangular cross section 0.6m wide and 0.25m deep. The flume test section is modified to reach the expanding ratio. Two sidewalls placed in the flume to form an expanding transition with a total fixed angle θ of 13° 26" as shown in Figure (2). The flaring walls are located on an elevated Plexiglas floor. The expanding transition has 0.54m long, 0.12m width at the upstream and 0.24m width represent the downstream flow. The side walls are constructed of painted wooden sheets to give a smooth surface. Eight piezometer taps along the center line of expanding transition are connected to the manometer board to indicate the bed pressure. A vertical sluice gate is located about 0.082m before the beginning of the expansion to produce supercritical flow. A tail gate is located at the end of the flume to control the tail water depth and the location of the radial jump. A centrifugal pump having a rated discharge of 15 lit/sec is used to deliver the flow to the flume. Six-pieces of wooden sill (used as baffle block): 235 mm, 200 mm, 165 mm length, and three of them with 15 mm height and others with 25 mm height. The baffle block is moved in the radial direction within the expanding transition, and located at the distance 515 mm, 360 mm, and, 210 mm from the gate respectively, Fig. (2).

The discharge is measured by using a pre-calibrated flow meter which is incorporated in the pump discharge pipe network. The measurements of depths are made by point gage mounted in instrument carriage. A current meter is used to measure the velocities. The range of the experimental data measured were: 1-discharge (1.98 to 10.5 lit/sec), 2-upstream Froude number (2.5 to 6.5), 3-sequent depth ratio $y_o = y_2 / y_1$ (2.1 to 7.1), and 4-sequent radius ratio $r_o = r_2 / r_1$ (1.2 to 2.3).

A typical test involved setting the discharge with the position of sill and gate opening, and then adjusting the tailgate until the jump will be stable. After the flow conditions are attained the conjugate water depths, length of jump, and the radii of the beginning and end of the jump are measured. The average free surface and the hydraulic gradient line along the bed are obtained. The upstream velocity of the jump is measured also. The procedure is repeated for each type and position of baffle block (sill), with different values of discharge.

ANALYSIS OF RESULTS

The results of this study are applicable for diverging stilling basin affected by baffle block with total divergent angle of θ equal to 13°26'.

Twenty-two experimental tests, involving 132 jump formations, were confirmed to form and manipulated relationships between the different parameters as shown in Figures (3) to (7).

In Figure (3) the sequent depth ratio, y_2/y_1, is plotted against the initial Froude number F_r, in the cases of floor with and without baffle blocks, for different sequent radius ratio, r_o. In the first case when the baffle blocks are not used, the sequent depth ratio is independent on sequent radius ratio. In the other case, with use baffle blocks, the sequent depth ratio y_2/y_1 is found dependent on, r_o. The variation of the effect of sequent radius ratio r_o on the sequent depth ratio y_2/y_1 increased with increasing the height of baffle blocks. In general, the sequent depth ratio increases with the increasing value of Froude number F_r, as well as increases when the sequent radius ratio increases.

Figure (4) illustrates the relationship between F_r, and the sequent depth ratio for different values of x/h. From that figure, it is concluded that as F_r increases the sequent depth ratio increases with the decreasing value of x/h.

In order to check if the length of R.H.J. are influenced by the changes- in horizontal distance and vertical height of baffle block x/h, the experimental data for sequent depth ratio and Froude number with different values of x/h, have been plotted in Figure (5). It is apparent from the figure that the jump length ratio increases with the increasing value of F_r while it decreases with the decreasing value of x/h.

Figure (6) illustrates the relationship between the length of R.H.J. and its height for different values of x/h. It is evident that as L_j increases the height of jump increases with increasing value of x/h. The relationships between length and height of R.H.J. can be obtained in linear forms as:

Without baffle blocks:

$L_j = 6\,h_j - 4.9$ For $2.5 \le F_r \le 6.5$ .... (13a)

With baffle blocks:

$L_j = 4.35\,h_j - 2.05$ For $2.5 \le F_r \le 6.5$ .... (13b)

A comparison is made between the obtained results in the case of basin without baffle blocks with the results obtained by the following equation given by [4]:

$L_j/y_2 = 4.75 - (4.20/F_r)$ .... (14)

It is found that there is a good agreement between both results, for example:

$L_j = 57.9$ cm from equation (13.a), and $L_j = 50.83$ cm from equation (14).

From experiments, it was observed that, the water surface profile for either subcritical or supercritical flow can be affected by using baffle blocks. Figure (7) illustrates the effect of baffle blocks on the surface of R.H.J. along the direction of flow. It is evident that, the location and the shape of the R.H.J. affected by the height and the location of the baffle blocks. On the other hand, the maximum water surface occurs just downstream the baffle blocks.

Figure (8) shows the relationship between F_r and the non dimensional ratio $\Delta E/E_1$ (the relative energy loss). It indicates that the energy loss ratio due to baffle block is proportional to x/h for a given Froude number, i.e., the relative energy loss decreases as the x/h decreases also the energy loss ratio decreases with the decreasing value of Froude number for a given x/h, reaching a minimum value when x/h = 8.4 because a part of energy is dissipated by sill.

Linear regression analysis

The length of jump at steady condition L_j, could be expressed as function of three parameters as given by the following derived formula:

$L_j/y_1 = 0.61\ (F_r)^{1.40}\ (x/h)^{0.32}\ (r_o)^{0.42}$ .... (15)

This equation has a multilinear correlation coefficient of 0.99. The computed values of L_j/y_1 using the above equation are plotted against the corresponding experimental data as shown in Figure (9).

CONCLUSIONS

Based on this study the following conclusions can be obtained:

- The length of R.H.J. (without baffle blocks) is related to Froude number, F_r and sequent radius ratios r_0, while length of R.H.J. (with baffle blocks) related to Froude number F_r, sequent radius ratio r_0, and relative distance x/h. The length of R.H.J. (with baffle blocks) is appreciably less than the corresponding length of R.H.J. (without baffle blocks) by about 25%.
- The sequent depth ratios in the R.H.J. (with baffle blocks) have lower values than those in R.H.J. (without baffle blocks). The sequent depth ratio decreases as the relative distance x/h increases.
- The head loss in a R.H J. affected by baffle blocks, which improve the energy loss. In other words it is a better energy dissipater than without baffle blocks.
- The effective relative distance x/h (from 34.30 to 8.40) provides a remarkable reduction in the relative energy loss ranges from 8% to 30% for Froude number F_r, less than 6.5. This reduction is reasonable from both economic and hydraulic point of view.
- An empirical equation described the relative length of jump L_j/y_1 as a function of F_r, x/h, r_o is obtained (equation 15), and may be valid in the similar conditions.

REFERENCES

[1] **Abdellateef, M.**: "Energy Dissipation D.S. Low Head Irrigation Structures Using Bed Roughness", Thesis presented to Ain Shams University, at Cairo, Egypt, in Partial Fulfillment of The Requirements for The Degree of Doctor of Philosophy, 1984.

[2] **Arbhabhirama, A. and Ablli, A.**: "Hydraulic Jump within Gradually Expanding Channel", Journal of the Hydraulic Division, ASCE, Vol. 97, No. HY1, Proc. Paper 7831, Jan., 1971, pp. 31-41.

[3] **Lawson, J.D.:** "Circular Hydraulic Jump", Journal of Hydraulic Engineering ASCE, Vol. 109, Paper No. 17889, April 1983.

[4] **Khalifa, A. Abdelkawi M. and Mccorquodale, John A.:** "Radial Hydraulic Jump", Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY9 Proc., Paper 14825, Sept., 1979, pp. 1065-1078.

[5] **Koloseus, H.J. and Ahmed D.:** "Circular Hydraulic Jump". Journal of the Hyd. Div., ASCE, Vol. 95, No. HY1, Proc. Paper 6367, Jan. 1969, pp. 409-422.

[6] **Mohamed Ali:** "Effect of Roughened Bed Stilling Basin on Length of Rectangular Hydraulic Jump", Journal of Hydraulic Engineering, ASCE, Vol. 117, No. 1, January, 1991.

[7] **Narayanan, R. and Schizas L.S.:** "Force on Sill of Forced Jump". J. Hydr. Div. ASCE, 106(7), 1980, pp. 1159-1193.

[8] **Rajarannam, N.:** "Hydraulic Jump". Advanced in Hydroscience, Chow, V.T., ed., Vol. 14, Academic Press, New York, and London, 1967, pp. 197-280.

[9] **Nettleton, P.C. and McCorquodale, J.A.:** "Radial Flow Stilling Basins with Baffle Blocks". Can. J. Civ. Eng. 16, 1989, pp. 489-497.

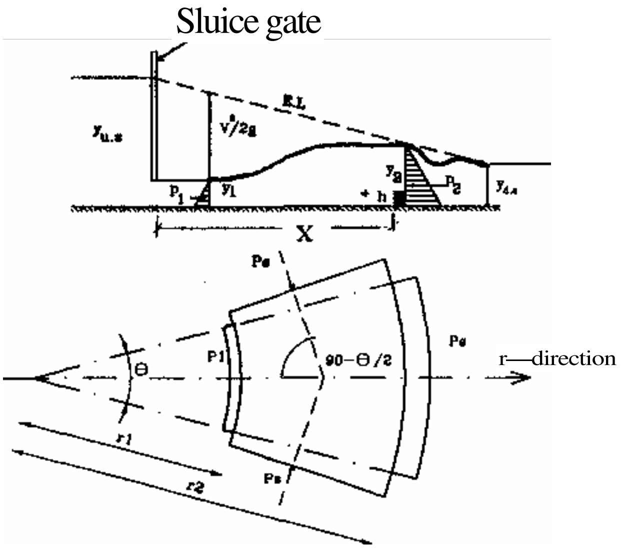
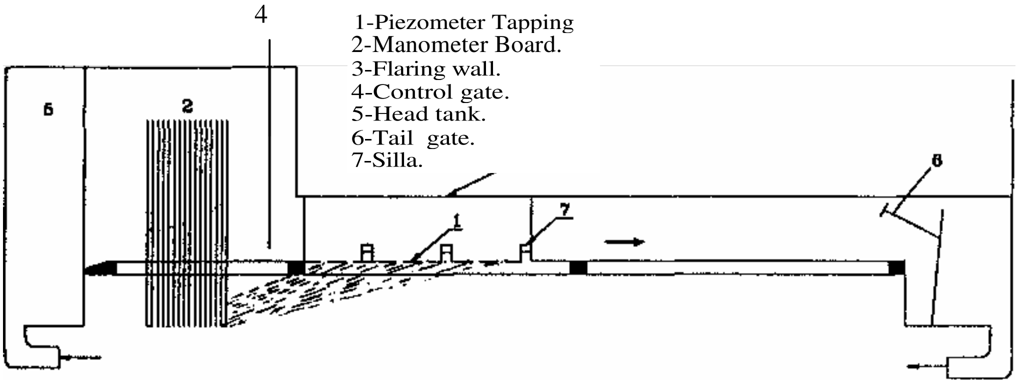
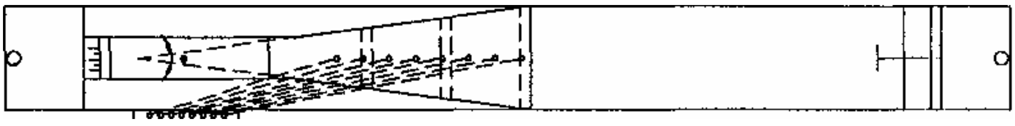


Figure (1): Definition sketch for radial hydraulic jump.

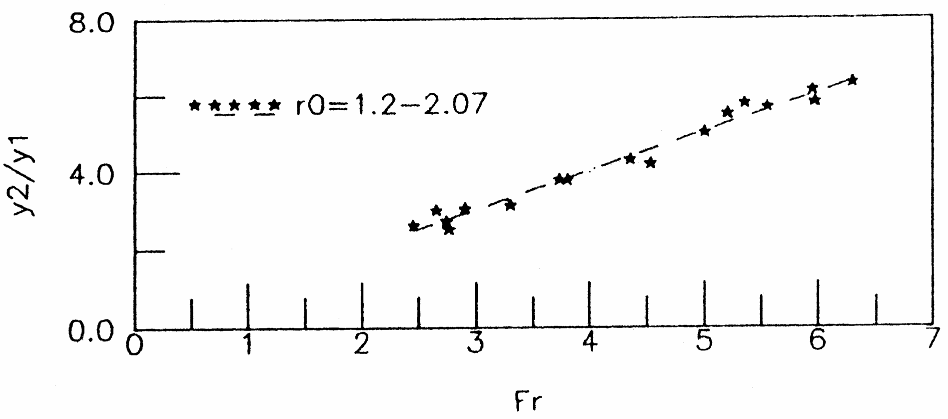


(a) Elevation

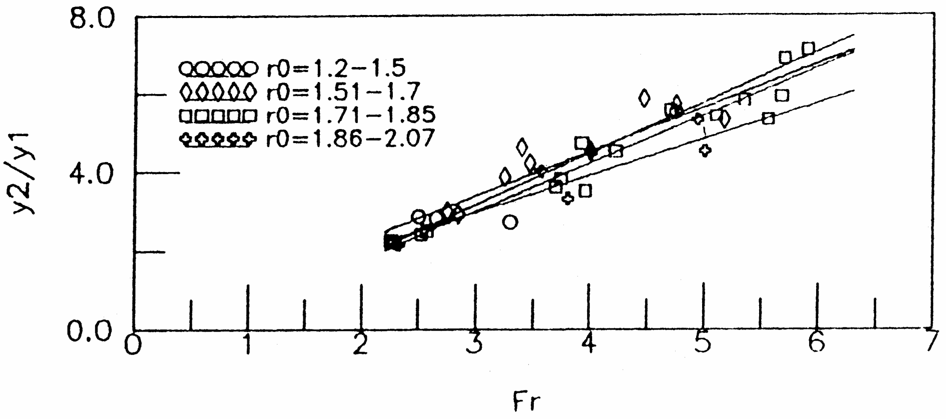


(b) Plan

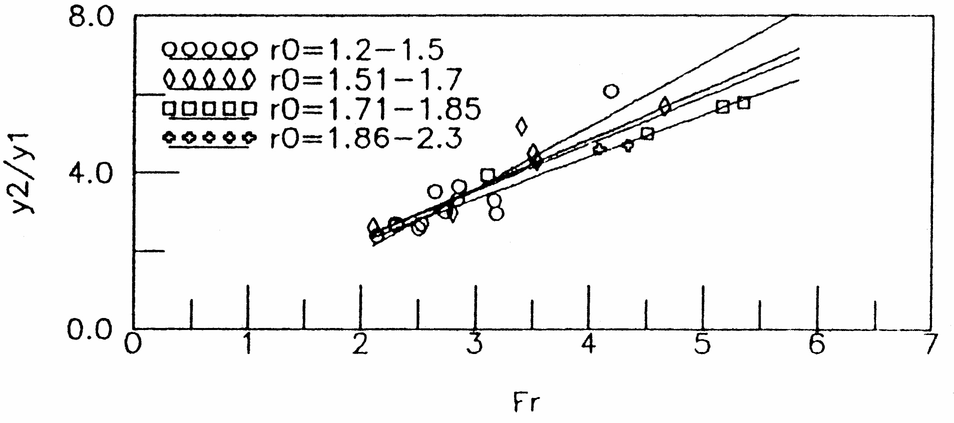
Figure (2) : Experimental Arrangement.



(a) Without baffle blocks



(b) h = 1.50 cm



(c) h = 2.5 cm

Figure (3) : Sequent depth ratio as function of initial Froude number for different values of radius ratio.

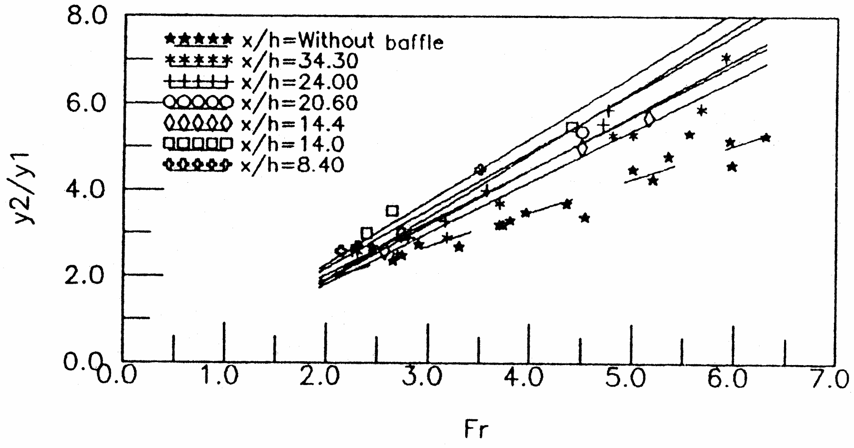


Figure (4) : Sequent depth ratio as function of initial Froude Number with different x/h.

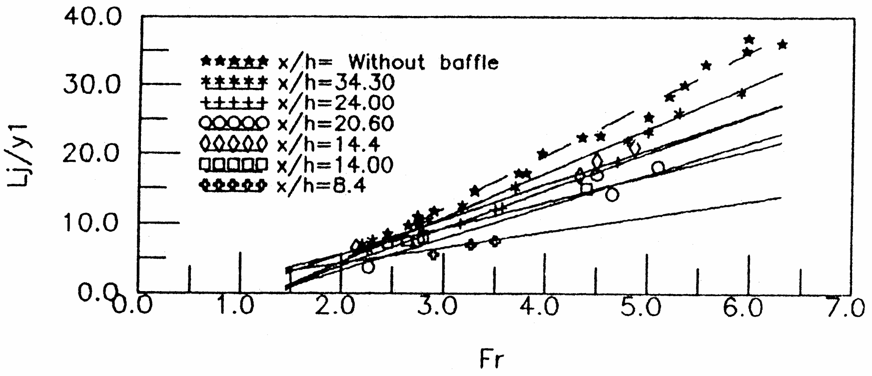


Figure (5) : Jump length ratio as function of initial Froude Number for different x/h.

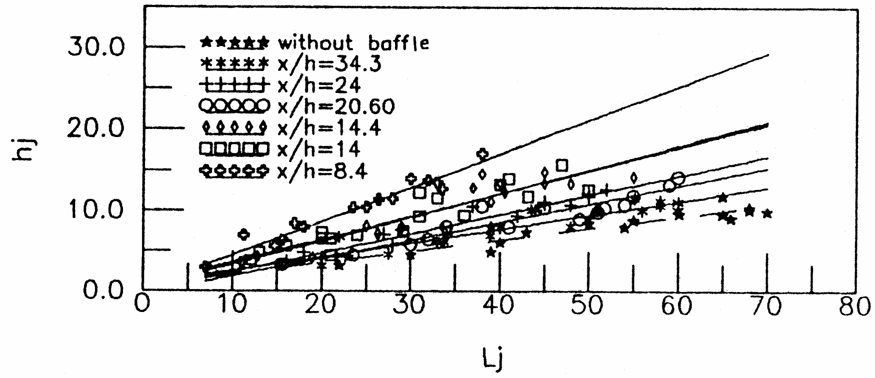
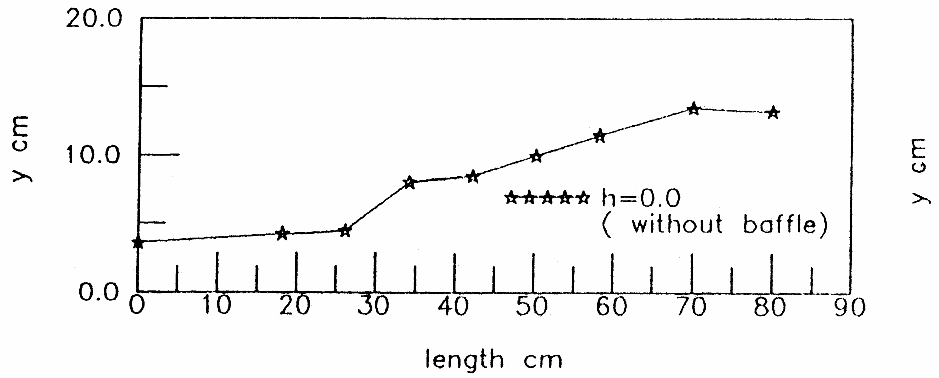
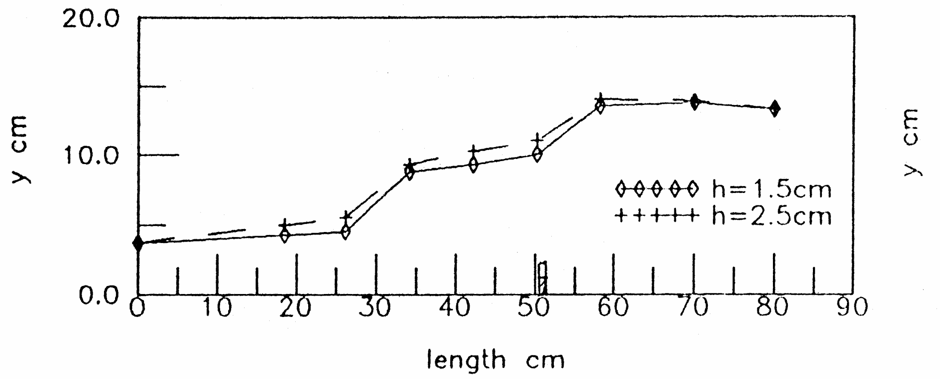


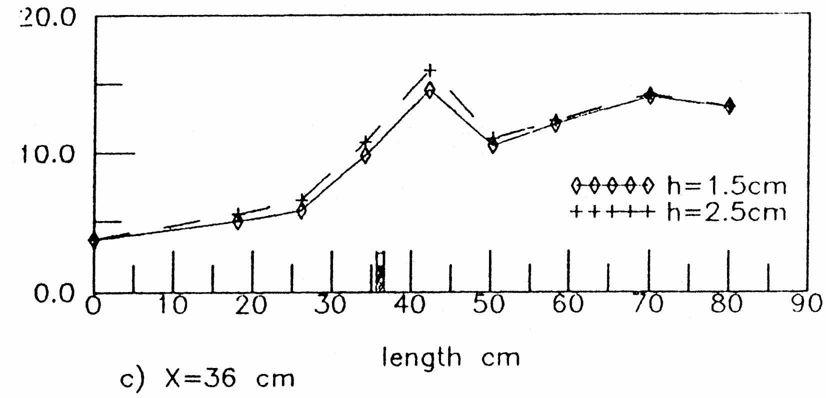
Figure (6) : Relationship between L_j and h_j for different values of x/h.



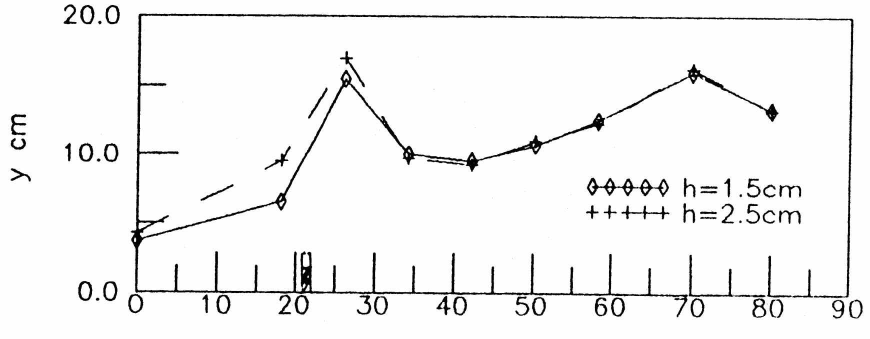
a) Without baffle block



b) X =51.5 cm



c) X=36 cm



d)x=21cm

Figure (7) : Effect of baffle blocks on the surface of R.H.J. along the length of flume.

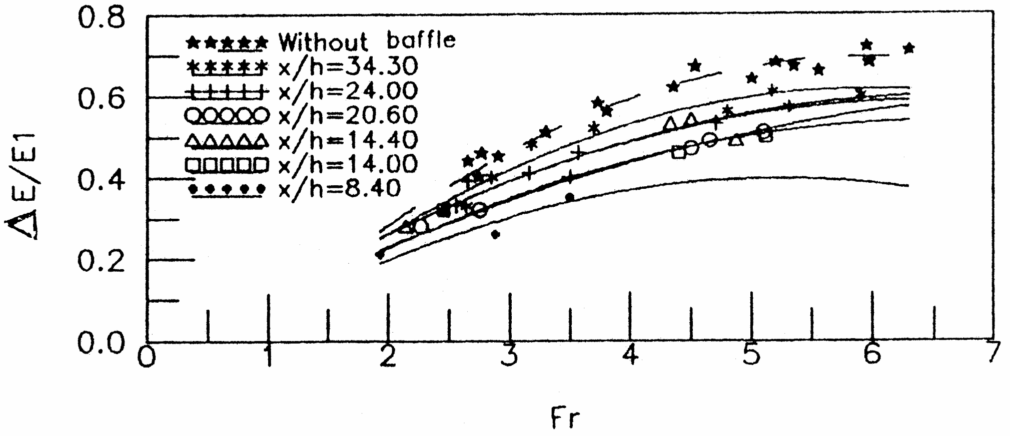


Figure (8) : Relative energy loss ΔE/E1 as a function of initial Froude Number for different values of x/h.

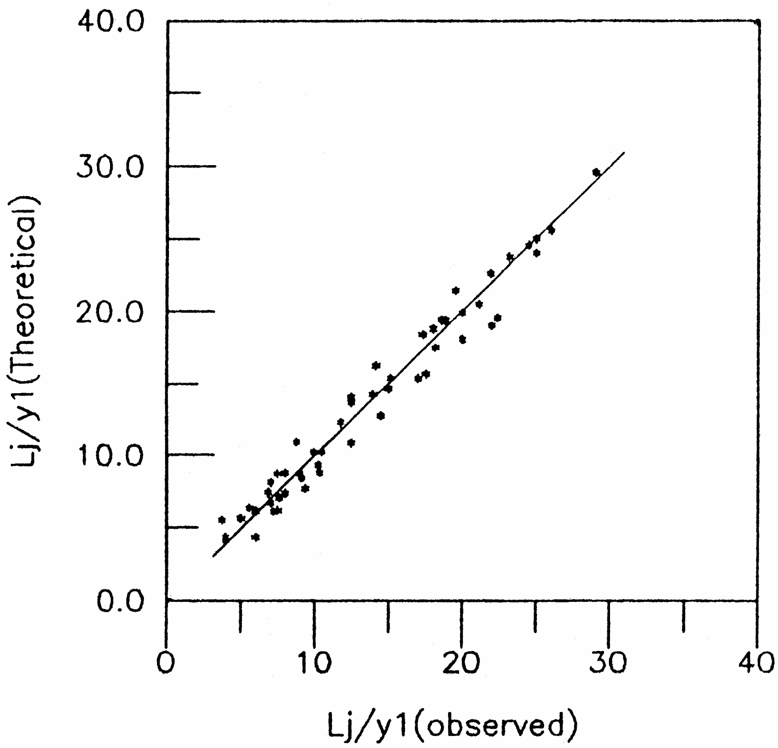


Figure (9) : Correlation between L_s/y_1 values,equation (15), and the corresponding observed onces.