Discussion on Paper 'Characteristics of hydraulic jump on rough bed with adverse slope' Authors: ParastooParsamehr, DavoudFarsadizadeh, Ali HosseinzadehDalir, AkramAbbaspour & Mohammad Javad Nasr Esfahani, Pub. online on 17 april,2017 in the ISH journal of hydraulic Engineering

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The paper is a basic research study on different characteristics of hydraulic jump e.g.(i)Conjugate depth relation (ii)length of jump (iii) relative energy loss etc. It is an experimental research work on jump on both horizontal and adversely sloping (1.5% i.e. $\theta=0.9^0$ and 2.5%i.e.$\theta=1.6^0$) floor. Two different roughness elements of heights (h=.014m and h= .028m) were introduced throughout the length of basin to roughenthe floor. Staggered roughness elements with a density of 10.67% were used such that the top of roughness elements coincided with the bed level by depressing the basin floor by an amount equal to roughness height. Experiments were performed for 7 different discharges with a constant pre-jump depth and the corresponding inflow Froude's number(F_{r1}) equal to 5.82,7.85,9.85,10.32,11.53, 12.21 &12.38 respectively. While horizontal basin floor was tested with both the roughness heights, the adversely sloping floor was provided with only one roughness height i.e. h=0.028m (Table-1 of the paper). Authors plotted the experimental and theoretical values of the conjugate depth (y_2/y_1), jump lengths (L_j/y_1) and energy loss (E_L/E_1) against pre-jump Froude's numbers (F_{r1}). They have also compared their results with previous research works on the subject. While y_2/y_1-values and L_j/Y_1-values reduces with adverse slope, energy loss (E_L/E_1) increases with slope of basin floor as compared with classical jump with horizontal floor for all the Froude's number of flow tested.

Using the momentum principles,the different characteristics of hydraulic jump on a sloping floor was determined from the basic jump equations derived by Argyropoulos(1962), Bakhmeteff et al(1938), Kindsvater (1944 and Kindsvater (1944). Jump characteristics were tested by Hager(1992) , RajaRatnam (1966) and many other research workers The basic equation of jump in a sloping apron can be written as

$$Y_2/y_1= ½[(8G_1^2+1)^{0.5} -1] \qquad \text{(Eq.1)}$$

where

$$G_1=F_{r1}/[\cos \theta +KL_j\sin\theta/(y_2-Y_1) \qquad \text{(Eq.2)}$$

where θ is the angle of inclination of the basin floor with horizontal and K is a coefficient governed by actual shape of jump profile which is assumed as linear in the derivation of Eq. (1) & Eq.(2). It may be noted that when $\theta=0$, $G_1=F_{r1}$, equation (1) becomes the same as classical jump equation (3)

$$y_2/y_1= ½[(8F_{r1}^2+1)^{0.5} -1] \qquad \text{(Eq.3)}$$

Knowledge of conjugate depth (y_2), length of hydraulic jump (L_j) and energy loss(E_L) are needed for design of stilling basins (Peterka,1958) for hydraulic structures e.g. dams, barrages etc.If the actual tail water depth (y_2') is less than the conjugate depth (y_2) given by Eq.(1), the jump is repelled.If the actual depth (y_2') is more than the conjugate depth, the jump is submerged. In case of repelled jump, energy dissipation within the basin will be low and there will be high erosion in the tail channel. Submergence of 5% to 6% may not create much problem. But high submergence results in poor performance of basin as there is no free jump. In submerged jump, the dipping jet adhering to the basin floor creates havoc downstream (Kawagashi et al 1990). Lot of study has been made on submerged jump characteristics on negatively sloping floor where conjugate depth requirement is higher than that in a classical jump on horizontal floor (Bradley et al,1957). Recently, Mohit Kumar et al (2015) have made exhaustive study on jump characteristics in a rough basin floor with –ve slope and compared their results with those obtained theoretically (Eq.1).

Study on hydraulic jump in a basin with +ve slope is limited and that way the paper is a valuable contribution to the subject. Such study are very useful for design of basin where available tail water depth (y_2’) is less compared to the conjugate depth required (y_2) in a classical jump with horizontal floor(θ=0).In such situation, it is usual to depress the basin floor by an amount ΔY (= Y_2-Y_2’) below river bed so that jump occurs within the basin. In case of bouldery rivers with steep bed slope where available tail water depth (y_2’) is usually low, such lowering of bed by excavation of boulders is difficult. Also, thickness of basin floor has to be increased to resist higher uplift pressure. Moreover, basin performance may not be satisfactory for flow lower than design flow as the jump will be submerged. In such a situation, basin with +ve slope will perform better.

Use of baffles/roughness elements on basin floor is helpful since the drag offered by such elements help in reduction of sequent depth for jump formation. In adversely sloping (+ ve slope) floor too, the weight component of jump act against flow thereby reducing conjugate depth (y_2) requirement and act similar to baffles and roughness elements used by the authors. However, at high Froude’s number (F_{r1}) where the inflow velocity is very high, the baffle blocks/roughness elements (introduced by the authors) may be subjected to cavitational damage requiring high cost of maintenance/replacement. As such, use of adverse slope is an effective method of controlling hydraulic jump where available tail water depth is less. Another merit of adversely sloping stilling basin floor is that the drag on the basin floor due to moving stones will reduce since the normal component of stone weight causing frictional drag will be lower compared to that in a horizontal floor. It is reported that the frictional drag offered by moving stones on a horizontal floor cause heavy damage to the basin.

Discusser performed a series of experiments to find hydraulic jump characteristics with both horizontal floor as well as floor with +ve slope as indicated in table-1. Variation of conjugate depth(y_2/y_1), length of jump & roller length((L_j/y_1&L_r/y_1) and relative energy loss(E_L/E_1) are plotted against pre-jump Froude’s no. of flow(F_{r1}) for different θ-values in Figs.1, Fig.2 and Fig.3 respectively. Conjugate depth (y_2/y_1) , jump & roller lengths(L_j/y_1&L_r/y_1) and relative energy loss (E_L/E_1) are found to increase with pre-jump Froude’s number (F_{r1}) for any given slope of basin floor (θ). Table-1 and Figs.1,2 &3 show that there is a substantial reduction of conjugate depth (y_2/y_1) requirement and jump length (i.e.basin length requirement) when slope of basin floor is increased. The relative energy loss (E_L/E_1) is however, increased considerably by increasing slope of basin floor. Thus, a stilling basin with adversely sloping (+ve slope) floor performs better than a basin with horizontal floor where classical hydraulic jump occurs.

Table-1 : Hydraulic Jump Characteristics on Horizontal and Sloping (+ve) Floor

θ	Q	y1	Fr1	y2/y1	y2/y1	Lj/y1	Lr/y1	EL/E1	REMARK
	(m3/s)	(m)		(Eq.1)	(Expt)	(Expt)	(Expt)		
0	0.0158	0.24	4.5	5.88	5.73	36	30.6	0.45	Free Jump
0	0.0158	0.02	6	8	7.73	49.2	41.5	0.57	Free Jump
0	0.0158	0.017	7.5	10.12	10.04	60.7	51.5	0.65	Free Jump
0	0.0188	0.125	9	12.24	11.96	73.7	62.4	0.71	Free Jump
2.5	0.0302	0.037	4.5	5.13	4.97	28.4	24.3	0.52	Free Jump
2.5	0.0258	0.0276	6	7.02	6.83	39.5	33.7	0.62	Free Jump
2.5	0.0158	0.0171	7.5	8.92	8.44	51.9	42.7	0.7	Free Jump
2.5	0.0119	0.0125	9	10.79	10.56	62.9	56	0.74	Free Jump
5	0.0302	0.0371	4.5	4.65	4.18	25.5	20.5	0.57	Free Jump
5	0.0258	0.0276	6	6.39	5.94	35.1	28.6	0.66	Free Jump
5	0.0158	0.0171	7.5	8.2	7.38	45	35.6	0.73	Free Jump
5	0.0119	0.0125	9	9.91	8.99	56.4	44	0.82	Free Jump
10	0.0302	0.0371	4.5	3.74	2.38	32.1	17.2	0.63	Submergd.Jump
10	0.0258	0.9276	6	5.18	3.38	46.6	26.1	0.74	Submergd.Jump
10	0.0158	0.0171	7.5	6.48	4.22	64.7	33.4	0.8	Submergd.Jump
10	0.0119	0.0125	9	8.21	5.3	74.4	39.2	0.84	Submergd.Jump

Note: L_r is the length of roller and L_j is the length of jump

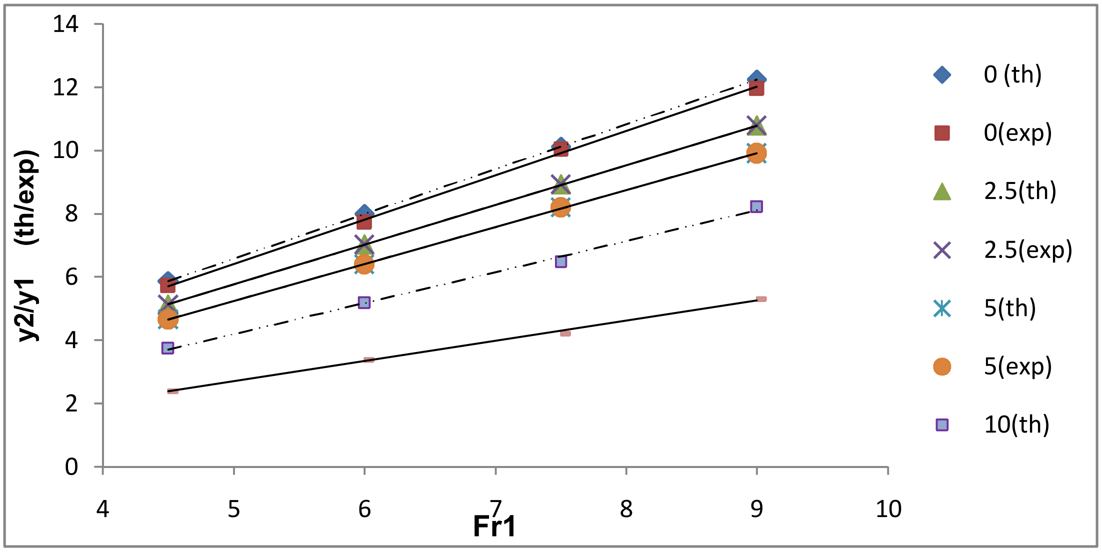

Fig.1 Showing Variation of y2/y1 with Fr1 For θ=0, 2.5, 5, & 10 Degrees

Note:0(th)&0(exp) stand for theoretical and experimental values of y_2/y_1 respectively in basin with 0^0 slope; 2.5(th)and 2.5(exp) stand for theoretical and experimental values in basin with 2.5^0 slope and so on

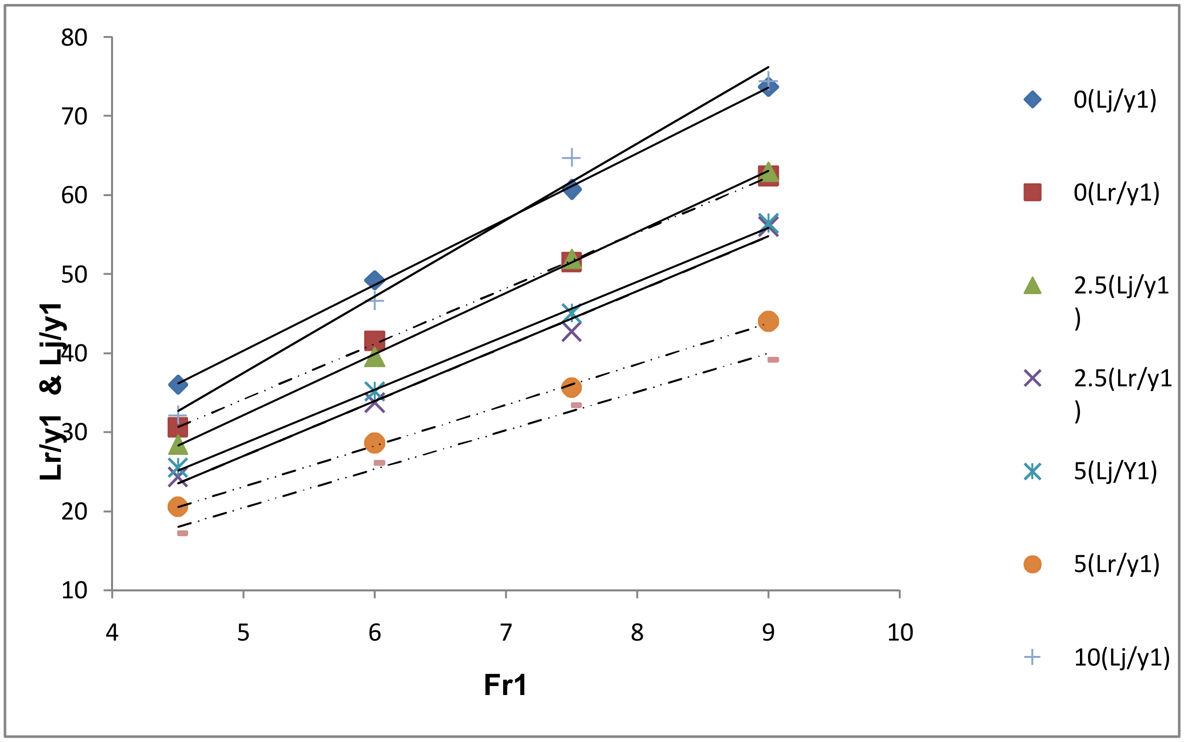

Fig.2 Showing Variation of L_j/y_1 &L_r/y_1 with Fr_1 For θ=0, 2.5, 5, & 10 Degrees

Note:0(L_j/y_1)&0(L_r/y_1) stand for jump length and roller length respectively in basin with 0^0 slope; 2.5(L_j/y_1)and 2.5(L_r/y_1) stand for jump length and roller length in basin with 2.5^0 slope and so on

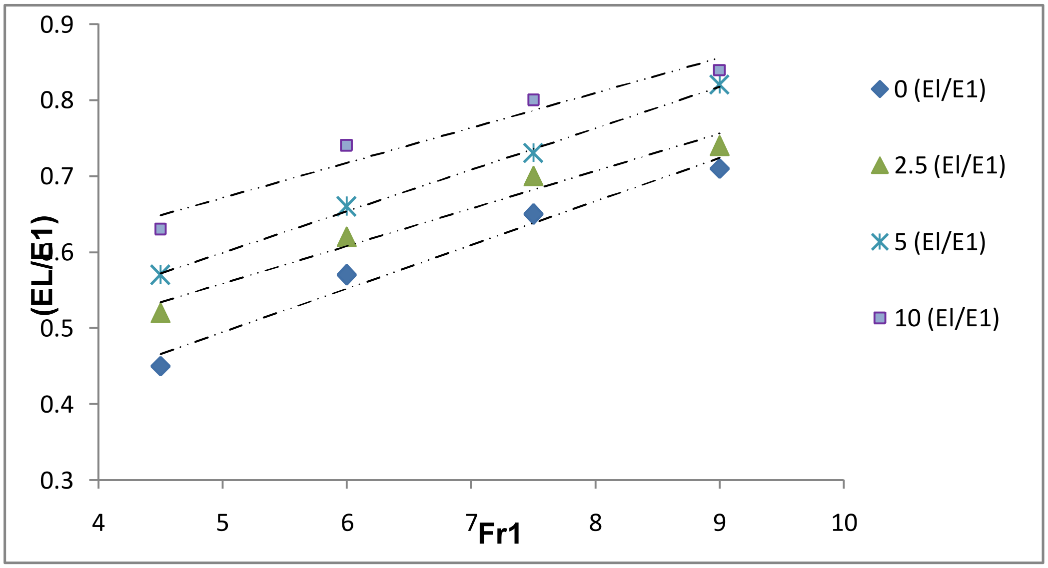

Fig.3 Showing Variation of E_L/ E_1 with F_{r1} For θ=0, 2.5, 5, & 10 Degrees

Note:0(E_L/E_1)&2.5(E_L/E_1) stand for E_L/E_1-values in basin with 0^0 and 2.5^0 slope respectively and so on

Discusser (Mazumder-2012,1994) developed a unique stilling basin for flumed structures like canal drops. In a classical basin with horizontal apron, the side walls are kept parallel to flow up to the end of basin followed by expansive transition which makes the structure very costly. In the innovative design, the side walls are diverged at 3:1 (Fig.4) so that the basin acts as energy dissipater and transition structure simultaneously. With horizontal floor, performance of the basin was found to be poor as the jump was skewed with little dissipation of energy within the basin. Hydraulic jump was stabilized and the basin performance was remarkably improved by providing adverse slope (β) to the basin floor such that the side wall reactions are exactly balanced by the bottom reaction from the jump weight. The adverse slope (β) of the non-prismatic basin to stabilize the jump can be expressed as

$$\beta = \tan\text{-}1[\,(y_1+y_2+y1\ y2)\tan\Phi\ /\ (b\ y2+By1+2by1+2By2)] \qquad \text{(Eq.4a)}$$

$$= \tan\text{-}1\ [2\ (y1/b)\tan\Phi\ (1+\alpha+\alpha^2)\ /\ (2+2\ \alpha\ r+\alpha+r)\ ] \qquad \text{(Eq. 4b)}$$

where,

$\alpha = y_2 / y_1$, $r = B / b$, y_1 and y_2 are the pre-jump and post- jump depths respectively, b and B are the half widths of the basin at the entry and exit respectively.The conjugate depth ratio, α=y_2/y_1 in this non prismatic stilling basin of rectangular section with adverse bed slope can be expressed bythe relation

$$F_{r1}^2 = 1/2\ [(1-\alpha^2 r)\ /\ (1-\alpha r)\ ]\ \alpha\ r \qquad \text{(Eq.5)}$$

In a prismatic channel of rectangular section when r =1 (i.e b=B and Φ=0) with horizontal floor β=0), equation (5) reduces to the conjugate depth relation in a classical hydraulic jump

$\alpha = y_2/y_1 = 1/2\ [(8F_{r1}^2+1)^{0.5}-1]$, i.e. the same as Eq.3

The basin was tested with different F_{r1}-values and discharge intensities (q=Q/2b) with different β-values to determine values of optimum basin slope (β_{opt}) when the jump was stabilized and performance was best. Fig.4 illustrates the optimum slope of the basin floor (β_{opt}) obtained experimentally which is almost same as β-value obtained from Eq.4(a) & 4(b).. Other performance characteristics of the non-prismatic basin are available elsewhere (Mazumder-1994, 2012).

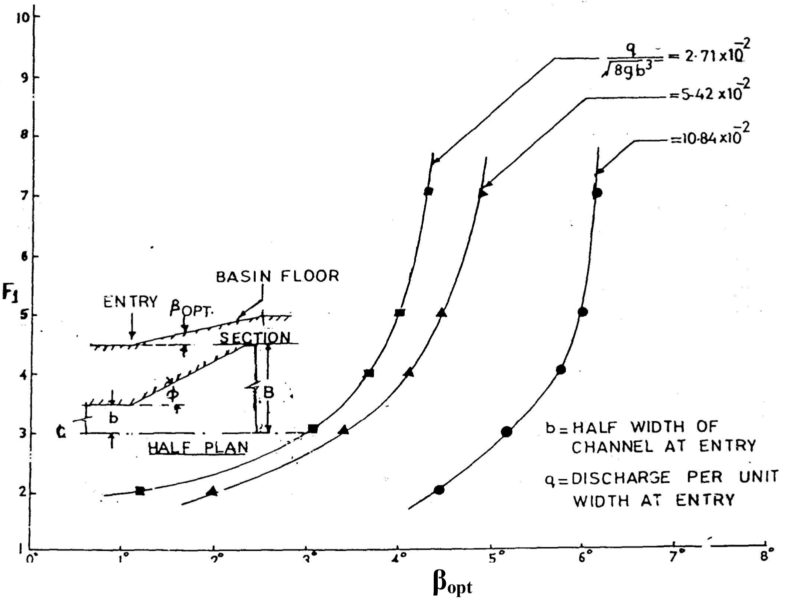

Fig.4 Optimum Inclination of Basin Floor($\beta_{opt.}$) for Different Values of Pre-jump Froude's No.F_1(=F_{r1}) from Expts.

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