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Experimental Study of Sequent Depths Ratios of Hydraulic Jump in Sloped Trapezoidal Channels

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ABSTRACT

The hydraulic jump in a sloped trapezoidal channel of 72.68° sidewall inclination angle was experimentally examined. The study aimed to determine the effect of channel slope on the sequent depths ratio of the jump. An experimental analysis is proposed to determine experimental relationships of the inflow Froude number as a function of the sequent depth ratio of the jump and the channel slope. For this purpose, positive and negative slopes were tested.

Keywords: *Hydraulic jump, trapezoidal channel, positive slope, adverse slope, open channels, stilling basins.*

1. INTRODUCTION

Hydraulic jumps are formed during the abrupt transition from supercritical to subcritical flow, when energy is dissipated. This phenomenon is invoked generally either downstream of a dam in order to dissipate the hydraulic energy or in water conveyance channels to rise the stream level. The hydraulic jump has been studied by many researchers such as Bradley and Peterka (1957), Hager and Bretz (1987), Hager (1992), and Ead and Rajaratnam (2002). Most studies focused on the hydraulic jump in horizontal rectangular channels. However, the first detailed study on the hydraulic jump in a rectangular channel with positive slope was carried out by Bakhmeteff and Matzke (1938), who examined the surface profile, the jump length, and the jump speeds distribution. Additionally, Kindsvater (1944) classified the sloped hydraulic jump, according to the position of the upstream edge of the jump with regard to the end of the slope, into four types: A-jump, in which the toe of the jump coincides with the downstream extremity of the slope; B-jump, in which the toe of the jump is between the A-jump and the C-jump; C-jump, in which the end of the jump roller coincides with the downstream extremity of the slope; and D-jump, in which the jump roller appears completely in the sloped portion. The D-jump was analyzed by Wilson (1970), Ohatsi and al (1973), Rajaratnam and Murahari (1974), and Mikhalev and Hoang (1976). Debabeche et al. (2009) have studied the hydraulic jump with positive slope in a triangular channel. Cherhabil (2010) subsequently developed, in her PhD thesis, the hydraulic jump with a positive slope in triangular and U-shaped channels. The most recent work on the hydraulic jump in a trapezoidal channel is that of Kateb (2014).

This study proposed an experimental research on the hydraulic jump in a sloped trapezoidal channel. The configuration adopted in this article corresponds to the D-jump type according to the classification of Kindsvater (1944). The objective is to determine the effect of the channel slope on the upstream sequent depth h_1 and downstream sequent depth h_2 for this jump configuration experimentally. However, empirical relationships are proposed relating the sequent depth ratio (Y) to the inflow Froude (F_1) and the channel slope (i).

2. EXPERIMENTAL SET-UP

Experimentation was carried out in a trapezoidal channel of 6 m length, 20 cm width, and 72.68° sidewall inclination with regard to the horizontal [see Figure 1]. Initial flow was generated by a set of five load boxes [see Figure 2] for which the opening heights correspond to the upstream sequent depths: h_1(mm) = 20, 30, 40, 50, and 60. For each chosen height h_1, six positive and two negative (adverse) slopes were tested so that the channel slope takes the following values, i(%): 0.005; 0.01; 0.015; 0.02; 0.00;-0.005 ;-0.01. Additionally, 22 thin sills of different heights *s* varying from 5 to 26 cm were used to control the hydraulic jump [see Fig. 3]. A practical range of inflow Froude numbers was obtained ($1 \leq F_1 \leq 14$).

Figure 1. Trapezoidal channel

Figure 2. Load boxes

Figure 3. Thin sills

3. Sequent Depth Ratio

Figures 4, 5, 6, 7, and 8 show the variation of the sequent depth ratio $Y = h_2/h_1$ as function of the inflow Froude number F_1 for seven slopes. Data analysis showed that a linear equation is possible for each value of the slope channel. This latter follows the form of $y = a\, i + b$.

Upstream Sequent Depth : h_1=20mm

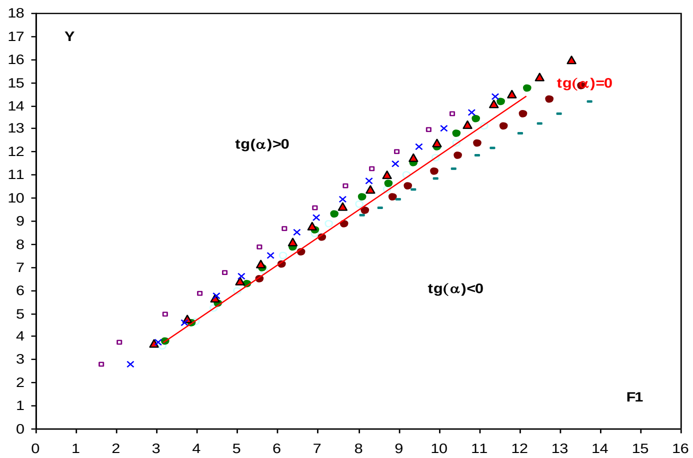

Figure 4. Variation of the sequent depth ratio as function the inflow Froude number for seven values of the channel slope *i=(●)0.005,(Δ) 0.01, (×) 0.015,(□) 0.02;(○) 0.00,(●)-0.005,(-)-0.01(—)*Trend Curve for *(◆) 0.00.*

Upstream Sequent Depth : h_1=30mm

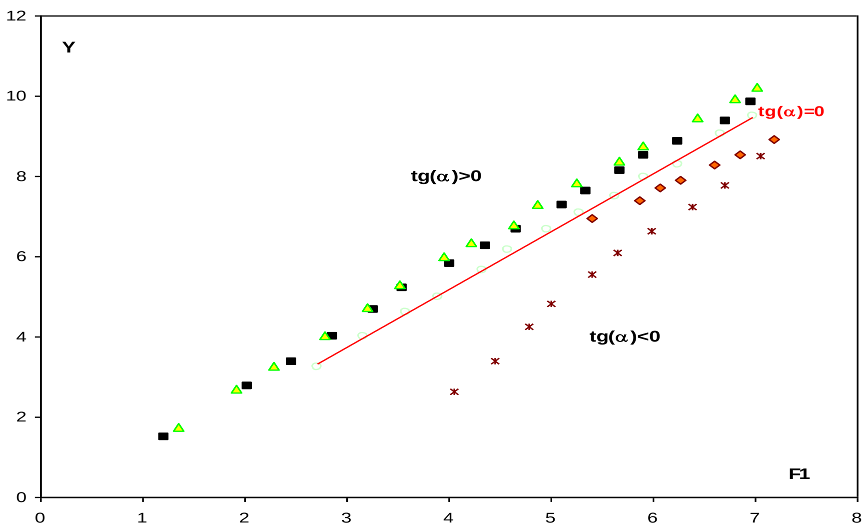

Figure 5. Variation of sequent depth ratio as function of the inflow Froude number for five values of the channel slope, such as *i=tg(α) = (□)0.005, (Δ) 0.01, (○) 0.00,(♦)-0.005,(*)-0.01.* (—)Trend Curve for *(♦) 0.00.*

Upstream Sequent Depth : h_1=40mm

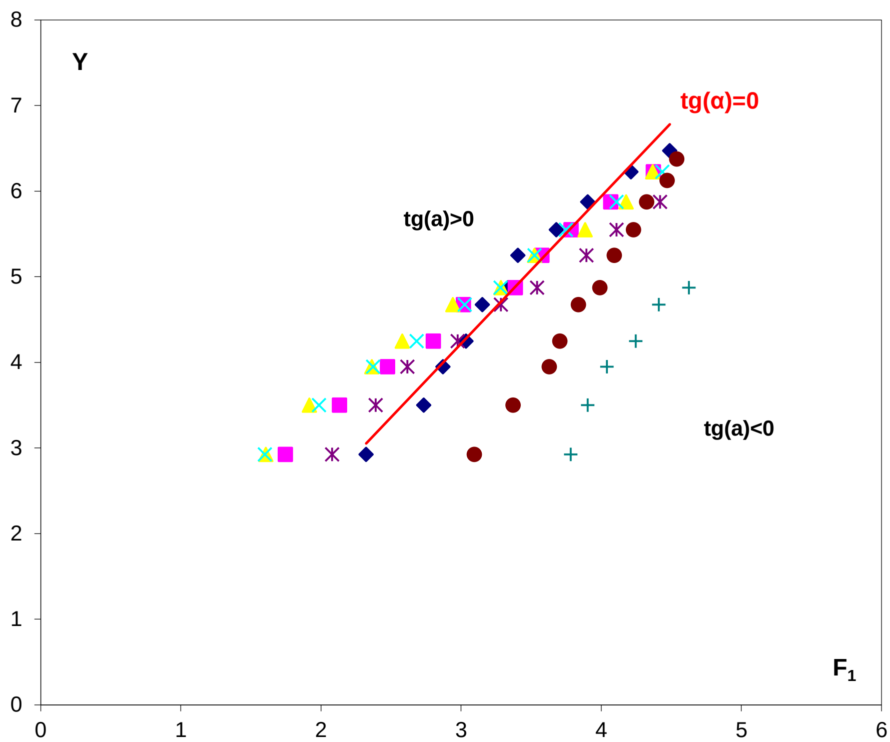

Figure 6. Variation of the sequent depth ratio as function of the inflow Froude number for seven values of the channel slope, such as *i=tg(α) = (*)0.005,(□) 0.01, (×) 0.015,(Δ) 0.02;(♦) 0.00,(●)0.005,(+)-0.0 .* (—)Trend Curve for *(♦) 0.00.*

Upstream Sequent Depth : h_1=50mm

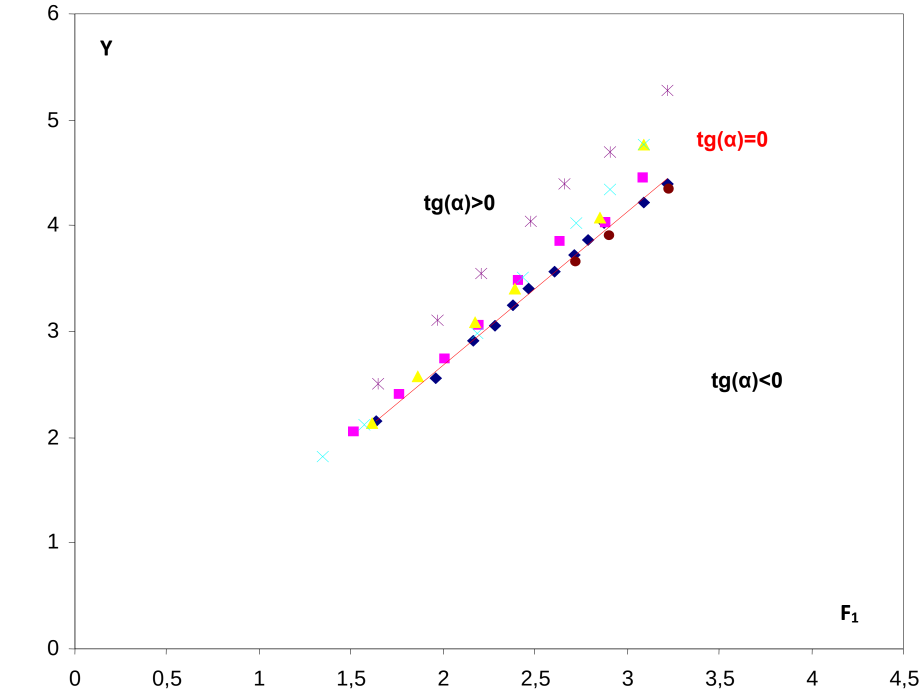

Figure 7. Variation of the sequent depth ratio as function of the inflow Froude number for six values of the channel slope *i=(□)0.005,(Δ) 0.01, (×) 0.015,(*) 0.02;(◆) 0.00,(●)0.005. (—)*Trend Curve for *(◆) 0.00.*

Upstream Sequent Depth : h_1=60mm

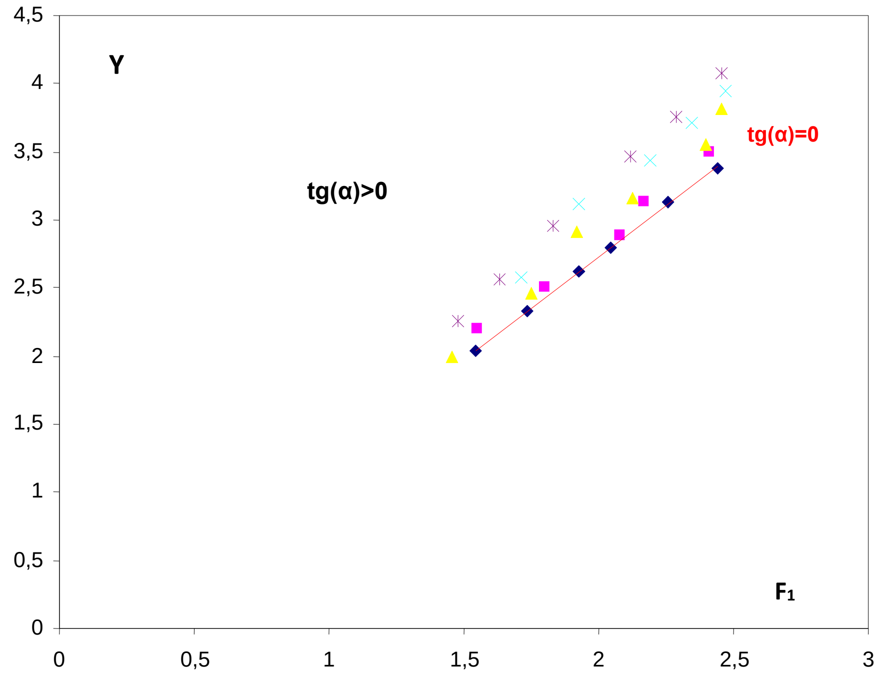

Figure 8. Variation of the sequent depth ratio as function of the inflow Froude number for five values of the channel slope, such as *i=tg(α) = (□)0.005,(Δ) 0.01, (×) 0.015,(*) 0.02;(◆) 0.00. (—)*Trend Curve for *(◆) 0.00* .

Table 1. Explicit relationships of variation of the sequent depth ratio, as function of the inflow Froude number and channel slope.

Initial depth h_1	Relation of Y_{app}	$i=tg\ \alpha$ (%)	F_1
20 mm	Y_{app}= (3.25 $tg(\alpha)$+1.17) F_1 + 39.65 $tg(\alpha)$ + 0.09	[0 - 2]	[3.1 - 3.6]
	Y_{app}= (13.1 $tg(\alpha)$+1.156) F_1 + 0.395	[-1 - 0]	[3.1 - 3.6]
30 mm	Y_{app}=(5,535 $tg\ (\alpha)$ + 1,446)F_1+(3,331 $tg\ (\alpha)$ + 0,082)	[0 - 2]	[4 - 8]
	Y_{app}=1,4/4F_1 -1,545	[-1 - 0]	[4 - 8]
40 mm	Y_{app}=(8,2 $tg\ (\alpha)$+ 1,032)F_1 -65,1 $tg\ (\alpha)$ +2,006	[0 - 2]	[1 - 5]
	Y_{app}=1,4/4F_1 -1,545	[-1 - 0]	[3 - 5]
50 mm	Y_{app}= (11,177 $tg\ (\alpha)$ + 1,521) F_1 + (24,7 $tg\ (\alpha)$ - 0,858)	[0 - 2]	[1 - 4]
60 m	Y_{app}= 17,134 $tg\ (\alpha)$ + 1,4789) F_1 - 15,243 $tg\ (\alpha)$ - 0,1152	[0 - 2]	[1 - 3]

Explicit relationships provide a simple way for determining the ratio of the combined heights *Y* by knowing the inflow Froude number F_1 and the value of the channel slope.

4. CONCLUSION

The hydraulic jump in a sloped trapezoidal channel was experimentally studied. The configuration of the jump adopted in this study corresponds to the D-jump. The experimental study focused on the variation of the relative height *Y*. The generalized relations obtained, express the sequent depth ratio *Y* as a function to the inflow Froude number F_1 and the channel slope *i*.

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6. LIST OF SYMBOLS

D Diameter of the channel [m]

F_1 inflow Froude number [-]

g acceleration of gravity [$m.s^{-2}$]

h_1 upstream sequent depth [m]

h_2 downstream sequent depth [m]

i channel slope ($i=tg(\alpha)$)

Q flow discharge [$m^3.s^{-1}$]

Y sequent depth ratio

α angle of inclination of the channel with regard to the horizontal [rad]