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ENERGY DISSIPATION ON STEPPED SPILLWAYS[A]

Discussion by Hubert CHANSON[2]

The author provided interesting data on stepped spillway flows. The writer would like to add some information on flow resistance of skimming flows and discuss the energy dissipation on stepped chutes. It will be shown that the author's results are not dissimilar with results previously obtained by other researchers (table A1).

FLOW RESISTANCE OF SKIMMING FLOWS

For skimming flows, horizontal vortices develop beneath the pseudo-bottom formed by the external edges of the steps. The vortices are maintained through the transmission of turbulent shear stress between the skimming stream and the recirculating fluid underneath.

If uniform flow conditions are reached along a constant slope channel, the friction factor can be deduced from the momentum equation as (CHANSON 1993) :

$$f = \frac{8 * g * \sin\theta * y_o^2}{q_w^2} * \frac{D_H}{4} \qquad [A1]$$

where f is the friction factor ($f = 4*C_f$), q_w is the discharge per unit width and D_H is the hydraulic diameter. For non-uniform gradually varied flows, the friction factor can be deduced from the energy equation:

$$f = \frac{8 * g * y^2}{q_w^2} * \frac{D_H}{4} * \frac{\Delta H}{\Delta s} \qquad [A2]$$

where ΔH is the total head loss over a distance Δs. (ΔH/Δs) is the friction slope.

The author re-analysed model data using equations [A1] and [A2]. Details of the flow conditions are reported in table A1. The results are presented in figure A1 where the friction factor f is plotted as a function of the relative roughness k_s/D_H, where the roughness k_s is defined as CHANSON (1993) (i.e. $k_s = h*\cos\theta$).

For channel slopes ranging from 50 to 55 degrees, figure A1 shows a large scatter of friction factor values observed on model. An analysis of all the data indicate no correlation between the friction factor, the Reynolds number and the relative roughness. It can be noted that the author's data are within the scatter of other data.

Figure A1 presents also results obtained for flows over rockfilled channels for a 30-degree slope (HARTUNG and SCHEUERLEIN 1970). The results indicate friction factors of similar order of magnitude as the results obtained on stepped spillways.

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It must be emphasised that the data were analysed neglecting the effects of air entrainment. No information is available on the amount of air entrained during these experiments.

ENERGY DISSIPATION

In skimming flow, most of the energy is dissipated in the maintenance of stable depression vortices (RAJARATNAM 1990). If uniform flow conditions are reached at the downstream end of the spillway, CHANSON (1993) showed that the total head loss can be rewritten in terms of the friction factor, the spillway slope, the critical depth and the dam height :

$$\frac{\Delta H}{H_o} = 1 - \frac{\left(\frac{f}{8 * \sin\theta}\right)^{1/3} * \cos\theta + \frac{1}{2} * \left(\frac{f}{8 * \sin\theta}\right)^{-2/3}}{\frac{H_{dam}}{y_c} + \frac{3}{2}} \qquad \text{[A3]}$$

where H_{dam} is the dam height (H_{dam} = N*h). Figure A2 compares equation [A3] with model data. Equation [A3] was computed for θ = 55 degrees and f = 1.30 as used by CHANSON (1993). Equation [A3] indicates that the energy loss ratio increases with the height of the dam. That trend, also observed on figure 4, is not "unexpected" (CHRISTODOULOU 1993) but was demonstrated previously by STEPHENSON (1991) and CHANSON (1993). Figure A2 shows a good agreement between the experimental data and equation [A3]. Again the author's data are within the scatter of the other model data.

It must be emphasised that equation [A3] depends critically upon the estimation of the friction factor. Figure A1 shows a large scatter of friction factor values observed on model. CHANSON (1993) showed that the friction factor and the rate of energy dissipation are affected significantly by the rate of aeration. Therefore equation [A3] must be used with caution.

APPENDIX I. REFERENCES

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APPENDIX II. NOTATION

D_H = hydraulic diameter (m);

f = Darcy friction factor;

H_{dam} = dam height (m);

k_s = roughness height (m) or step dimension normal to the flow : $k_s = h * \cos\alpha$;

q_w = water discharge per unit width (m^2/s);

s = distance (m) along the channel from the crest;

Table A1- Characteristics of model studies

Reference (1)	Slope (deg.) (2)	Scale (3)	Step height h (m) (4)	Nb of steps (5)	Discharge q_w (m^2/s) (6)	Remarks (7)
SORENSEN (1985)	52.05	1/10	0.061	11	0.006 to 0.28	Monksville dam spillway model (USA). W = 0.305 m.
		1/25	0.024	59	0.006 to 0.28	
BAYAT (1991)	51.3	1/25	0.024 0.03 0.02		0.006 to 0.07	Godar-e-landar spillway model (Iran). W = 0.3 m.
DIEZ-CASCON et al. (1991)	53.1	1/10	0.03 - 0.06	50 to 100	0.022 to 0.28	(Spain). W = 0.8 m.
STEPHENSON (1991)	54.5					Kennedy's vale model (South Africa).
PEYRAS et al. (1992)	18.4, 26.6, 45	1/5	0.20	3, 4, 5	0.04 to 0.27	Gabion stepped chute (France). W = 0.8 m.
BINDO et al. (1993)	51.34	1/21.3	0.038	31 - 43	0.01 to 0.142	M'Bali spillway model (France).
		1/42.7	0.019	43	0.007 to 0.04	W = 0.9 m.

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Fig. A1 - Friction factor of skimming flow

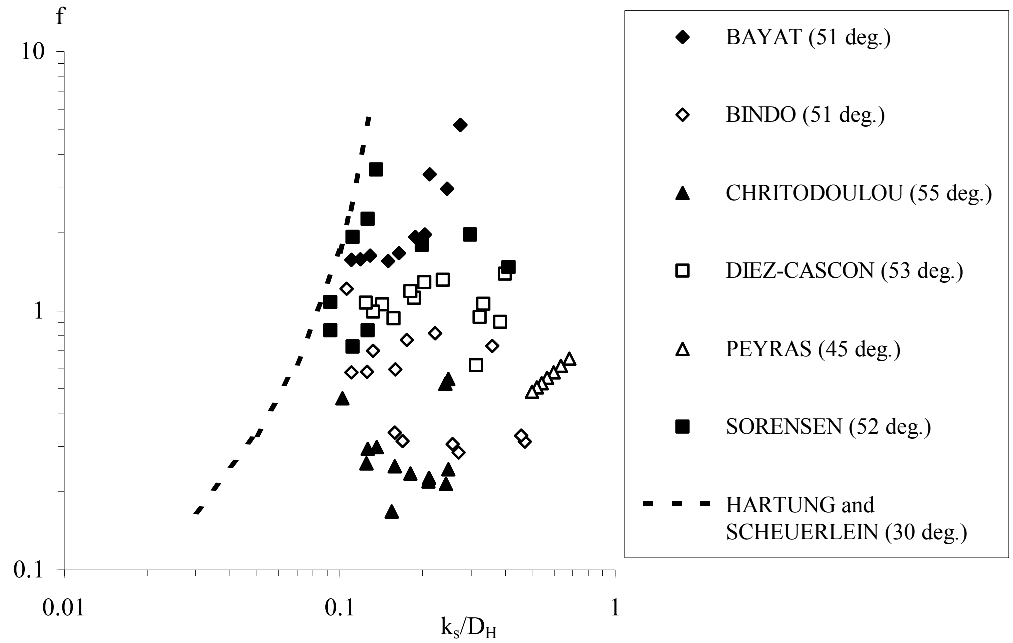

Fig. A2 - Energy dissipation in skimming flow regime