ENERGY DISSIPATION THROUGH HYDRAULIC JUMP

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SYNOPSIS

The subject of Energy dissipation below spillways and other hydraulic structures is of vital importance to irrigation and hydraulic engineers particularly in view of the increased tempo of construction of such structures these days all over the world.

There are several devices through which the desired energy dissipation may be accomplished but the most effective one seems to be through the formation of hydraulic jump below such structures. The usual practice is to have a channel of rectangular shape for hydraulic jump device perhaps for ease of computation. It has, however, been found recently and reported by Silvester as well (1) that the use of non-rectangular channels with sloping wall is the most suitable on account of extra loss available in channels of such section and the economy of construction of sloping walls. Further by expressing the basic equations in terms of suitable non-dimensional parameters as outlined in this paper, the computation work is greatly simplified. For future designs, channels with sloping sides are, therefore, recommended.

Notation: The letter symbols adopted for use in this paper are given in the text where they first appear and are also arranged alphabetically in Appendix I for convenience of reference.

General: One of the most important considerations in the design of a spillway section or similar other hydraulic structure is the method of controlling erosion of the river bed down-stream of the structure. The problem is essentially one of reducing the high velocity of flow just below the structure to a velocity low enough to prevent undesirable erosion of natural bed down-stream. The device which accomplishes this is usually called energy dissipator and the structure which contains this velocity reducing action is commonly known as stilling basin.

<u>**Hydraulic Jump Stilling Basin Device:**</u>

This is one of the most effective devices of energy dissipation. In India this device has been provided in several important structures such as Bhakra Dam Spillway, Mettur Dam Spillway etc. The energy dissipation efficiency of this device can be easily ascertained from the general equation for energy loss in hydraulic jump in prismatic channels expressed in the non-dimensional form as:

$$\frac{E_L}{E_1} = \frac{2 - \frac{2d_2}{d_1} + F_1^2 \frac{\delta_1}{d_1}\left(1 - \frac{A_1^2}{A_2^2}\right)}{2 + F_1^2 \frac{\delta_1}{d_1}} \quad \text{-- -- (1)}$$

$$F_1^2 = \frac{Q^2 T_1}{g A_1^3} \quad \text{-- -- (2)}$$

The various symbols used here have the following meanings:

E_L = loss of energy in jump
E_1 = energy before jump
d_1 = depth before jump
d_2 = depth after jump
A_1 = area of flow before jump
A_2 = area of flow after jump
T_1 = water surface width corresponding to depth d_1
$\delta_1 = \frac{A_1}{T_1}$
Q = rate of flow
g = acceleration due to gravity

and F_1 is called the initial Froude number. The prismatic channels most commonly found in practice are: The rectangular and the trapezoidal channels. Sometimes the parabolic and the triangular shaped channels are also used. Channels of rectangular and parabolic shape (Figs. 1a, 1b and 1 c respectively) come under the classification of exponential channels defined by the equation

$$A = Cd^m \quad \text{-- -- (3)}$$

where C is a proportionality constant and m is an exponent. For rectangular channels having width B (Fig. 1a)

$$C = B \quad \text{-- -- (4 a)}$$
$$m = 1 \quad \text{-- -- (4 b)}$$

For parabolic channels defined by the Eq. $T = kd^{1/2}$

$$C = \tfrac{2}{3}k \quad \text{-- -- (5 a)}$$
$$m = 1.5 \quad \text{-- -- (5 b)}$$

For triangular channels, having sides slopes 1 vertical to n horizontal.

$$C = n \quad \text{-- -- (6 a)}$$
$$m = 2 \quad \text{-- -- (6 b)}$$

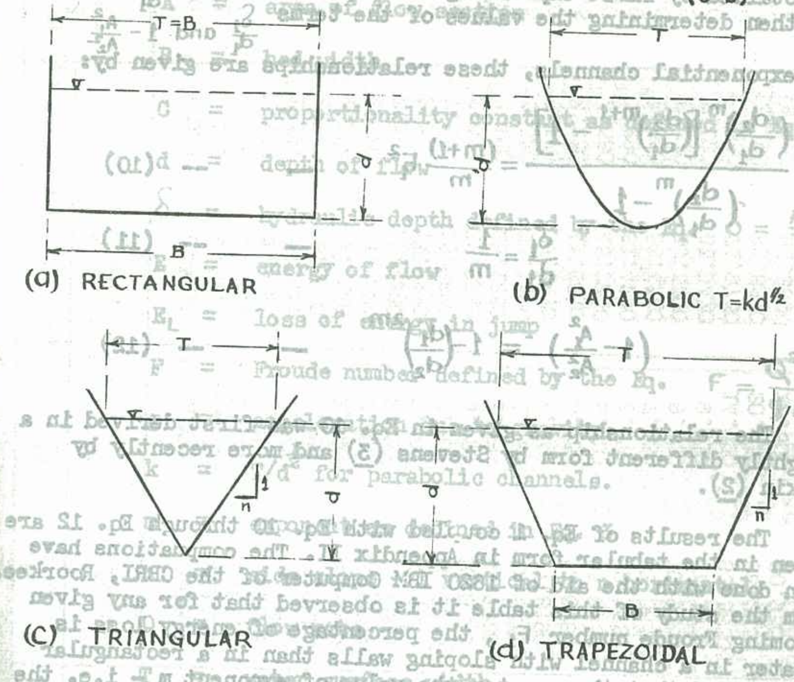

Fig.1

The trapezoidal channels (Fig. 1.d) are normally classified as non-exponential, but it has been shown by Diskin (2) recently that for all practical purposes they can be approximated to exponential channels defined by the equation

$$\frac{A}{B^2} = C\left(\frac{d}{B}\right)^m \quad \text{-- -- (7)}$$

which when coupled with the usual expression for cross sectional area A in the non-dimensional form - viz.

$$\frac{A}{B^2} = \frac{d}{B} + n\left(\frac{d}{B}\right)^2 \quad \text{-- -- (8)}$$

gives the value of exponent m as

$$m = \frac{1 + \frac{2nd}{B}}{1 + \frac{nd}{B}} \quad \text{-- -- (9)}$$

Thus the exponential equation given under Eq. 3 may be considered to apply to all practical forms of open channels.

Now from Eq. 1, the relation between $\frac{E_L}{E_1}$ versus F_1 may be obtained by first expressing the relation between $\frac{d_2}{d_1}$ and F_1 and then determining the values of the terms $\frac{\delta_1}{d_1}$ and $1-\frac{A_1^2}{A_2^2}$. For exponential channels, these relationships are given by:

$$\frac{\left(\frac{d_2}{d_1}\right)^m\left[\left(\frac{d_2}{d_1}\right)^{m+1}-1\right]}{\left(\frac{d_2}{d_1}\right)^m-1} = \frac{(m+1)}{m}F_1^2 \qquad \text{—— —— (10)}$$

$$\frac{\delta_1}{d_1} = \frac{1}{m} \qquad \text{—— —— (11)}$$

$$\left(1-\frac{A_1^2}{A_2^2}\right) = 1-\left(\frac{d_1}{d_2}\right)^{2m} \qquad \text{—— —— (12)}$$

The relationship as given in Eq. 10 was first derived in a slightly different form by Stevens (3) and more recently by Diskin (2).

The results of Eq. 1 coupled with Eq. 10 through Eq. 12 are given in the tabular form in Appendix II. The computations have been done with the aid of 1620 IBM Computer of the CBRI, Roorkee. From the study of this table it is observed that for any given incoming Froude number F_1, the percentage of energy loss is greater in a channel with sloping walls than in a rectangular channel and that the greater the value of exponent m - i.e. the more the channel approaches the triangular shape, the greater is the energy loss. This together with the economy in the construction of sloping walls may be taken advantage of in the future design of hydraulic jump stilling basin devices. However before such a design is freely recommended, extensive laboratory studies may be carried out on the problems of symmetry length of jump and transverse profile of water before and after the jump.

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APPENDIX I

NOTATION

A	=	area of flow section
B	=	bed width
C	=	proportionality constant as defined in Eq. 3
d	=	depth of flow
δ	=	hydraulic depth defined by the Eq. $\delta = \frac{A}{T}$
E	=	energy of flow
E_L	=	loss of energy in jump
F	=	Froude number defined by the Eq. $F = \frac{Q^2 T}{g A^3}$
g	=	acceleration due to gravity
k	=	$T/d^{\frac{1}{2}}$ for parabolic channels.
m	=	exponent as defined in Eq. 3
n	=	side slope - 1 vertical to n horizontal
Q	=	flow rate
T	=	water surface width
1,2	=	subscripts denoting conditions before and after the jump respectively.

REFERENCES

(1) Silvester, R. - "Hydraulic Jump in all shapes of Horizontal Channels" Proc.ASCE, Journal Hyd.Div. Vol.90, No.HY1, Part I, p.23 (Jan.1964).

(2) Diskin, M.H. - "Hydraulic Jump in Trapezoidal Channels" Water Power, Vol. 13, No.1, p. 12 (Jan. 1961).

(3) Stevens, J.C. - "The Hydraulic Jump in Standard Conduits"- Civil Engineering, Vol.3, No.10, p.565 (Oct.1933).

RELATIONSHIP BETWEEN $\frac{d_2}{d_1}$, F_1 AND $\frac{E_L}{E_1} \times 100$ FOR DIFFERENT VALUES OF EXPONENT m

$\frac{d_2}{d_1}$	m = 1·0 F_1	m = 1·0 $\frac{E_L}{E_1}\times 100$	m = 1·2 F_1	m = 1·2 $\frac{E_L}{E_1}\times 100$	m = 1·4 F_1	m = 1·4 $\frac{E_L}{E_1}\times 100$	m = 1·5 F_1	m = 1·5 $\frac{E_L}{E_1}\times 100$
1.0	1.000	0.0000	1.000	0.0000	1.000	0.0000	1.000	0.0000
1.2	1.149	0.1004	1.170	0.1445	1.190	0.1965	1.201	0.2255
1.4	1.296	0.6211	1.340	0.8913	1.390	1.2092	1.510	1.3859
1.6	1.442	1.6544	1.510	2.3638	1.582	3.1926	1.630	3.6509
1.8	1.587	3.1465	1.700	4.4700	1.690	6.0010	1.850	6.8410
2.0	1.732	5.0000	1.860	7.0551	2.000	9.4036	2.080	10.6800
2.2	1.876	7.1146	2.040	9.9638	2.210	13.1750	2.320	14.9000
2.4	2.020	9.4024	2.200	13.0630	2.430	17.1280	2.550	19.2850
2.6	2.160	11.7920	2.400	16.2500	2.640	21.1210	2.800	23.6740
2.8	2.310	14.2270	2.580	19.4440	2.880	25.0550	3.030	27.9580
3.0	2.450	16.6670	2.760	22.5930	3.110	28.8630	3.290	32.0660
3.5	2.810	22.6040	3.220	30.0440	3.680	37.6070	3.940	41.3530
4.0	3.160	28.1250	3.680	36.7050	4.290	45.1150	4.160	49.1610
4.5	3.520	33.1400	4.150	42.5430	4.890	51.4530	5.300	55.6280
5.0	3.870	37.6470	4.640	47.6190	5.530	56.7810	6.000	60.9730
5.5	4.230	41.6810	5.130	52.0280	6.150	61.2710	6.750	65.4100
6.0	4.580	45.2900	5.550	55.8650	6.800	65.0730	7.500	69.1180
7.0	5.290	51.4290	6.570	62.1620	8.160	71.0980	9.050	74.8930
8.0	6.000	56.4140	7.550	67.0640	9.450	75.5980	10.600	79.1210
9.0	6.710	60.5200	8.520	70.9560	10.920	79.0480	12.300	82.3080
10.0	7.420	63.9470	9.610	74.1040	12.310	81.7560	14.000	84.7740
15.0	10.950	74.9730	14.890	83.5830	19.900	89.4200	22.600	91.5500
20.0	14.490	80.8840	20.250	88.2250	28.000	92.8660	32.000	94.4720
25.0	18.030	84.5500	25.800	90.9300	36.800	94.7570	43.500	96.0310

Values of F_1 have been taken from Table III p.16 Reference (2)

APPENDIX II (Contd.)

RELATIONSHIP BETWEEN $\frac{d_2}{d_1}$, F_1 AND $\frac{E_L}{E_1} \times 100$ FOR DIFFERENT VALUES OF EXPONENT m

$\frac{d_2}{d_1}$	m = 1·6 F_1	m = 1·6 $\frac{E_L}{E_1}\times 100$	m = 1·8 F_1	m = 1·8 $\frac{E_L}{E_1}\times 100$	m = 2·0 F_1	m = 2·0 $\frac{E_L}{E_1}\times 100$
1.0	1.000	0.0000	1.000	0.0000	1.000	0.0000
1.2	1.212	0.2565	1.245	0.3244	1.260	0.4003
1.4	1.440	1.5744	1.485	1.9865	1.541	2.4454
1.6	1.670	4.1379	1.750	5.1967	1.840	6.3658
1.8	1.900	7.7288	2.030	9.6417	2.160	11.7280
2.0	2.140	12.0190	2.310	14.8720	2.490	17.9350
2.2	2.400	16.6960	2.620	20.4740	2.850	24.4560
2.4	2.660	21.5110	2.920	26.1310	3.220	30.9060
2.6	2.940	26.2860	3.250	31.6280	3.600	37.0400
2.8	3.220	30.9000	3.600	36.8690	4.000	42.7270
3.0	3.500	35.2830	3.940	41.6810	4.420	47.9120
3.5	4.210	45.0350	4.820	52.1190	5.510	58.7110
4.0	4.980	53.0610	5.800	60.3430	6.690	66.8550
4.5	5.750	59.5820	6.790	66.7760	8.130	72.9870
5.0	6.580	64.8830	7.850	71.8330	9.280	77.6520
5.5	7.400	69.2170	8.910	75.8480	11.360	81.2530
6.0	8.980	72.7910	10.010	79.0750	12.140	84.0760
7.0	10.100	78.2660	12.300	83.8590	15.200	88.1320
8.0	11.900	82.1960	14.900	87.1650	18.600	90.8350
9.0	13.800	85.1100	17.700	89.5400	22.200	92.7180
10.0	15.900	87.3330	20.400	91.3020	25.900	94.0790
15.0	26.800	93.2690	35.600	95.7590	47.500	87.3470
20.0	38.600	95.7270	53.300	97.4630	73.100	98.5040
25.0	51.500	97.0020	72.600	98.3000	102.000	99.0420