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IMPROVED DESIGN OF A PROPORTIONAL FLOW METER

by
S.K. Mazumder[1], M.ISH and **Indroniel Deb Roy[2]**

ABSTRACT

Conventional flow meters have several drawbacks which were overcome in the improved design. Geometry of the control section of the flow meter was determined theoretically in order to maintain normal depth - discharge relation upstream. Model dimensions were computed from prototype canal with a scale of 1:30. The improved flow meter has high modular limit and nearly constant coefficient of discharge under free flow condition. Conventional expansive transition provided at the outlet of the flow meter was replaced by straight expansion. Studies were made with four different lengths of expansion governed by side splays 0:1, 1:1, 2:1 and 3:1. With level bed, the hydraulic performance of expansions defined in terms of efficiency (η_0) and Coriolis coefficient (α_2) were found to be extremely poor. Separation of flow occurred right from the entry of the expansions resulting in highly non-uniform velocity downstream. By providing adverse slopes to the expansion floor, performance of the flow meter was found to improve remarkably. Adverse slopes were found theoretically by means of equations developed earlier by the first author. With provision of adverse slope, separation was completely eliminated and velocity distribution was highly uniform in all the cases.

KEY WORDS : Canals, Flumes, Hydraulic efficiency, Expansions, Separation, Adverse slope, Velocity distribution.

INTRODUCTION

Flow meter is needed for measurement of discharge in open channel. Different types of flow meters commonly used are weirs and notches, venturis, standing wave flumes etc. The normal depth - discharge relationship in the channel upstream of the flow meters gets affected due to construction of the structure. Flow meters in which there is a free flow and the discharge can be expressed as an unique function of the upstream head are known as proportional type flow meters. The study reported herein pertains to a proportional type flow meter in which the throat width and hump height are designed in such a way that the depth - discharge relationship upstream of the flow meter can be maintained for different flows.

In all flow meters, the channel is flumed for the purpose of economy. The flumed section, also known as the control section, is connected to the original section of the channel by providing a pair of contracting and expanding transitions in order to reduce erosion and also for obtaining smooth flow without undesirable disturbances. However, such classical transitions

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1. AICTE Emeritus Fellow, Deptt. of Civil Engg., Delhi College of Engg., Delhi, India.
2. Software Engineer, 1420 Apptt. A, 23rd North Street, Wisconsin Rapids, USA.

Note : Written discussion of this paper will be open until 30th June, 1999.

are not only costly, they are hydraulically inefficient also. Flow is found to separate from the walls of the expanding transition resulting in nonuniform distribution of velocity downstream. In the present study, a short curved contraction having an average side slope of 2:1 was provided. The expansion consisted of straight walls having splays varying from 1:1 to 3:1. Separation which invariably occurs is such wide angle straight expansion with level bed were controlled by providing adverse slope to the channel bed as proposed by Mazumder (1994).

A flow meter is said to be modular type when the flow is choked for the range of discharges for which it is designed. In a non-modular type flow meter, there is no choking of flow. Non-modular flow meter is also termed as submerged type flow meter. The advantage of a modular type flow meter is that the discharge can be expressed as an unique function of upstream head and the coefficient of discharge of such flow meters are not affected by the downstream geometry of the meter and the tail water level. In a non-modular type flow meter, however, the discharge coefficient is affected by both the upstream as well as the downstream geometry of the flow meter and the water level downstream. The measurement of water level in the downstream reach is never accurate because of the fluctuation of the tail water level resulting in inaccurate measurement of flow. The flow meter under study has high modular limit ensuring free flow for the given range of discharge.

There will be always some difference in the energy levels in the upstream and downstream of a flow meter. It is therefore, necessary to ensure that the energy difference is entirely dissipated. Otherwise, the undissipated energy will cause nonuniform flow and erosion in the downstream reach. In the classical design of a flow meter, the energy dissipator provided upstream of expansion is a separate unit. In the present study the dissipating unit is combined with expansion by flaring the side walls of the flow meter immediately downstream of the control section. The new flow meter has high modular limit and the flow changes from critical to subcritical stage without any jump. The problem of energy dissipation, therefore, is not so important.

REVIEW OF LITERATURE AND OBJECTIVE OF THE STUDY

A summary of various types of flow meters are given in the publications by Ackers and Harrison (1978), King (1954), Bos (1975), Ranga Raju (1993), Subramanya (1986). Parshall flume (1950) and Cut throat flume are the commonly used venturi type critical flow meters. All the flow meters are designed for a particular discharge. In Cipoletti weir, the side slope and the bottom width are so adjusted that the depth - discharge can be maintained at least for two different flows. However, this flow meter is not so popular nowadays. Moreover, the hypothesis of dividing the flow into two parts namely, the flow over a rectangular notch of length equal to bottom width of the weir and flow through a triangular notch, can not be theoretically explained.

The study reported herein was primarily directed towards development of a proportional type flow meter where the throat width (B) and level of the crest at the control section were so designed that the depth - discharge relationship could be maintained in the channel upstream of the flow meter for a given range of flow.

HYDRAULIC PERFORMANCE CRITERIA

The various criteria governing the performance of flow meters, such as, coefficient of discharge (C_d), modular limit, efficiency of transition (η) and Coriolis coefficient (α_2) were calculated to demonstrate the improved performance of the flow meter. These are explained briefly below.

Coefficient of Discharge

Discharge was computed by using the classical equation

$$Q = C_d . B H_c^{3/2} \tag{1}$$

where Q = discharge, B = width of the throat, H_c = energy head over crest. Equation (1) is universally used by hydraulic engineers for computation of flow in a flow meter. C_d-value may vary from 1.5 $m^{1/2}/s$ (rectangular weir) to 2.16 $m^{1/2}/s$ (ogee weir). In venturi flumes, C_d-value ranges from 1.45 $m^{1/2}/s$ (for abrupt entry) to 1.7 $m^{1/2}/s$ (for smooth curved entry). Further information can be obtained from Ackers (1978). Higher is C_d value, more efficient is the flow meter.

Modular Limit

Modular limit of a flow meter helps in determining whether the flow is free or submerged. The modular limit of a critical flow meter is governed by the limiting tail water depth when the flow just begins to be submerged. For more information, Mazumder (1991) can be seen. Higher the modular limit, more efficient is the flow meter.

Efficiency of Inlet Transition

The main function of the inlet transition is to convert the potential energy at the upstream section to kinetic energy at the control section. For an ideal case, there is no energy loss due to friction and the entire potential energy is converted to the kinetic energy at the control section. potential energy lost is given by $\Delta y_{(1-c)}$ i.e. the difference in water level between upstream (1-1) and the control section (c-c) (Fig. 1). Gain in kinetic energy of flow is given by $[(V_c^2 - V_1^2)/2g]$. where, V_c and V_1 are the mean velocities of the flow in the control and upstream sections respectively. Efficiency of inlet transitions is given by ;

$$(\eta_i) = [(V_c^2 - V_1^2)/2g]./\Delta y_{(1-c)} \tag{2}$$

It can be shown that the inlet energy loss coefficient $C_i (= h_{L,i} / (V_c^2/2g - V_i^2/2g))$ is related to efficiency by the expression ;

$$\eta_i = 1/(1 + C_i) \tag{2a}$$

It is apparent from Eq. (2a) that lower the loss of energy in the inlet transition, lower will be C_i and higher will be efficiency η_i.

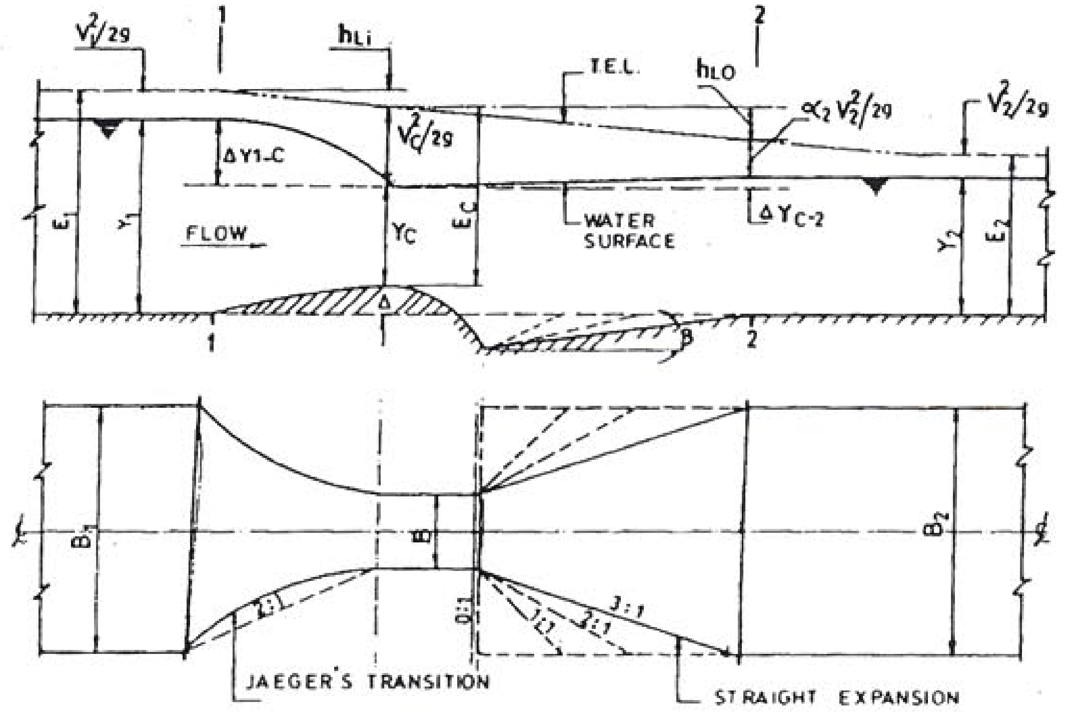


FIG. 1. PLAN & SECTION VIEW OF FLOW METER
(SHOWING CONTROL SECTION (C - C), CONTRACTING & EXPANDING TRANSITIONS, ADVERSE SLOPE (β) OF EXPANSION FLOOR, ENERGY LOSSES (h_{Li} & h_{Lo}), CRITICAL DEPTH Y_c, CORIOLIS COEFF. (α_2))

Efficiency of Outlet Transition

The main function of an outlet transition is to recover the kinetic energy at the throat to the potential energy at the exit of expansion. For an ideal condition, there is no energy loss due to friction and separation. The ideal recovery of head $\Delta y_i = \left[(V_c^2 - V_2^2)/2g\right]$ (Fig. 1). In actual practice, however, there will be some energy loss h_{Lo} and the actual recovery $\left[\Delta y_{(2-c)}\right]$ will be less than the ideal one. The efficiency of outlet transition is given by ;

$$\eta_o = \Delta y_{(2-c)} / \left[(V_c^2 - V_2^2)/2g\right] \tag{3}$$

It may be proved that the outlet energy loss coefficient $C_o\left(= h_{Lo}/(V_c^2/2g - V_2^2/2g)\right)$ is given by

$$\eta_o = 1 - C_o \tag{3a}$$

It is apparent from Eq. (3a) that lower is the energy loss in outlet, lower will be C_o and higher will be the efficiency η_o.

Coriolis Coefficient

Apart from the hydraulic efficiencies of the transition, another important criterion governing the performance of the flow meter is the distribution of velocity at the exit of the outlet transition. If the velocity distribution at the exit is nonuniform, the bed and the sides of the channel downstream are likely to be eroded unless costly protective measures are provided. Coriolis Coefficient, also known as Kinetic Energy Correction factor (α_2) is an index which defines the non-uniformity of low at the exit of the outlet transition. The Coriolis Coefficient α_2 may be expressed as ;

$$\alpha_2 = \left[\int u^3.dA\right] / (A_2.V_2^3) \tag{4}$$

where u = velocity through elementary area dA, A_2 = Cross-sectional area of flow at the exit of expansion, V_2 = Mean velocity of flow downstream of expansion. Higher is the value of α_2, more is the non-uniformity of the velocity distribution and more will be the erosion downstream. Referring to Fig. 1, the residual kinetic energy of flow $\left[(\alpha_2 - 1)V_2^2 / 2g\right]$ can be contained by the flow through distortion in velocity. An expansion is hydraulically more efficient when $\alpha_2 \approx 1$.

THEORY OF PROPOSED FLOW METER

As already mentioned earlier, the proportional type flow meter under study is a combination of a weir and a venturi. Critical height of a weir is determined to cause choking at the highest discharge. It will automatically remain free for discharges smaller than the design discharge, resulting in loss of depth - discharge relation in the back water reach upstream. Critical throat width of a flume, on the other hand, is determined by the minimum discharge for causing choking of flow. For discharge higher than the design value, the flow will always remain free. It well, however, cause afflux in the upstream reach resulting in loss of depth - discharge relation upstream. In the proposed flow meter, where the choking is achieved by a suitable combination of weir and venturi, there will be no afflux except that due to frictional losses upstream. The meter remains free and the normal depth - discharge relation is maintained for the design flow-range. Since there will be very little afflux, the requirement of energy is minimal. The design is based on critical specific energy principle. Referring to Fig. 1, $(E_1 - \Delta) = E_c$, where E_1 is the specific energy available in the upstream of the structure. Δ is the difference between crest level and bed level and E_c is the critical specific energy available in the control section. Let E_{1max} and E_{1min} be the specific energies available corresponding to the discharges Q_{max} and Q_{min} respectively. Writing E_c in terms of discharge and width of the control section, Eqs. (5) & (6) below can be obtained

$$(E_{1max} - \Delta) = 3/2\left[(Q_{max}^2 / B^2)/g\right]^{1/3} \tag{5}$$

$$(E_{1min} - \Delta) = 3/2\left[(Q_{min}^2 / B^2)/g\right]^{1/3} \tag{6}$$

Solving Eqs. (5) & (6) simultaneously, B and Δ are found by Eqs. (7) & (8) below :

$$B = \left[0.7(Q_{max}^{2/3} - Q_{min}^{2/3}) / (E_{1max} - E_{1min})\right]^{3/2} \tag{7}$$

$$\Delta = E_{1max} - 3/2\left[(Q_{max}^2 / B^2)/g\right]^{1/3} \tag{8}$$

INLET AND OUTLET TRANSITIONS

An outlet transition connecting the normal mean width of flow (B_1) with the throat width (B) was constructed to minimize head loss. Jaeger's (1956) method was used for the design of inlet transition with an average side splay 2:1.

Outlet transition is one of the most important component of the flow metering structures. Many expansive transitions have been proposed by engineers and researchers, namely, Hinds (1928), Chaturvedi (1963), Mazumder (1977), Vittal (1983), Garde and Nashta (1988), Swamee (1992) in the past. Hydraulic performance of these classical transitions are not satisfactory. Flow separation occurs in these transitions resulting in low hydraulic efficiency (η_o) and high Coriolis coefficient (α_2) at the exit. Straight expansion with adversely sloping bed was found to be very effective by Mazumder (1994). He computed adverse slope β value of the expansion floor given by Eqs. (9) and (10) below :

$$\beta = \tan^{-1}\left[(2.Y_c / B)\left\{(\delta^2+\delta+1)/(2+\delta+\lambda+2\lambda\delta)\right\}\ldots.\tan\theta\right] \tag{9}$$

$$\delta^3 - \delta(\lambda + 2.\ \lambda.\ F_2^{\ 2}) + F_2^{\ 2}.\ \lambda = 0 \tag{10}$$

where $\delta = Y_c / Y_2$, $\lambda = B_1 / B$ and F_2 is the Froude number of flow downstream.

MODEL DIMENSIONS

The proportional flow meter under study is designed for a canal. Various prototype data are i) maximum discharge in the canal $Q_{max} = 99.1\ m^3/s$, ii) full supply depth of water corresponding to maximum discharge in the canal = 3.629 m, iii) longitudinal slope of the canal = 1:8000, iv) Manning's roughness coefficient n = 0.025, v) minimum discharge in the canal = 25 m³/s, vi) side slope of the canal = 1:1, vii) mean bed width of the canal B_1 = 29.87 m. Values of B and Δ for the prototype flow meter corresponding to the above flow parameters were computed by using Eqs. (7) & (8) and were found to be 8.62 m and 0.10 m respectively.

Based on the above data, a model was prepared in the Advanced Hydraulics Laboratory of Delhi College of Engineering. The flume on which the experiments were performed was a tilting flume 9 m long, 1 m wide and 0.6 m deep. Water was taken from an underground tank by means of a centrifugal pump of 15 H.P. capacity. Venturimeter calibrated by a volumetric tank was used for measuring the discharge. Because of the discharge and the width constraints, a model scale of 30 was chosen. The model dimensions were calculated on the basis of Froude law of similarity. The model dimensions and flow parameters corresponding to the prototype are given as under :

(i) Q_{max} = 20 lps (ii) Q_{min} = 5 lps (iii) Y_{2max} = 120.9 mm (iv) Y_{2min} = 50 mm
(v) B = 290 mm (vi) B_1 = 1000 mm and (vii) Δ = 3.3 mm.

EXPERIMENTAL RESULTS

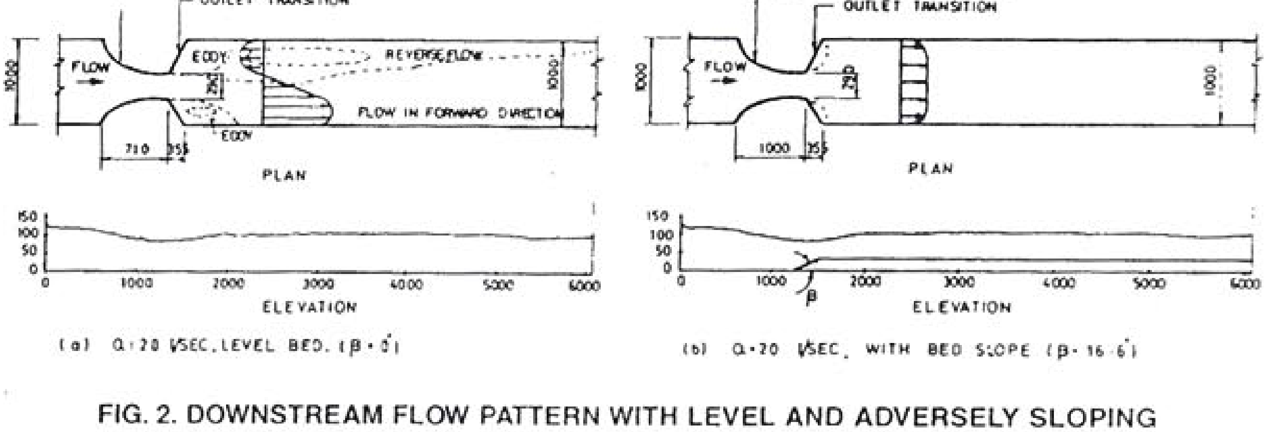
Various performance characteristics of the flow meter e.g. coefficient of discharge (C_d), modular limit, η_i, η_o, α_2 and flow pattern downstream are given in Table-1. Experiments 1 to 12 were performed with level bed in expansion ($\beta = 0^0$) while experiments 13 to 21 were performed in expansion with adversely sloping bed having β-value equal to 16.6^0, 8.48^0 and 5.67^0 corresponding to side splay 1:1, 2:1 land 3:1 respectively.

As seen from column 5 of Table-1, the C_d values of the flow meter varied in the range 1.67 - 1.73 under free flow condition. C_d was more or less independent of side splay of expansion downstream of control section as expected, C_d values were found to increase slightly with decrease in flow for all side splays. C_d value was independent to adverse bed slope after control section.

Modular limit of the flow meter is given in column - 6 of Table-1. It is obvious that the flow meter had a high modular limit varying from 0.98 at 3:1 side splay to 0.90 for 0:1 side splay. With adverse slope, modular limit was found to be in the range 0.92 to 0.98 i.e. same as in the case of level bed.

The efficiency of inlet and outlet transition calculated by equations (2) and (3) are given in columns 7 and 8 of Table-1. The inlet efficiency η_i was found to vary from 86% to 99%. Outlet efficiency η_o of expansion with level bed ($\beta = 0^0$) was found to vary from 28% (for abrupt) to 54% (for 3:1) side splay. With the provision of adverse slope, there was a phenomenal rise in outlet efficiency ranging between 90.0% (for 1:1 side splay) to 99% (for 3:1 side splay). η_o increased with reduction of flow.

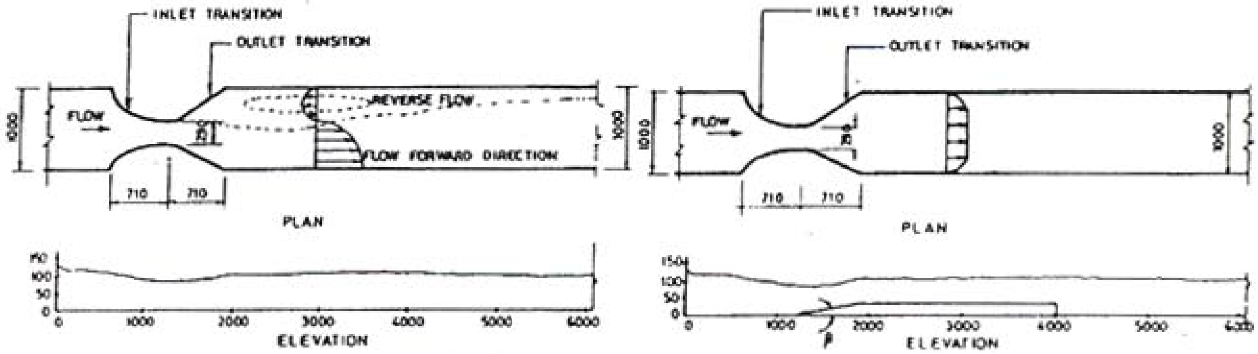
Isovels were plotted from the measured velocities at the exit of expansion. Coriolis coefficient (α_2) were computed for Q = 20 lps from the isovels with equation 4. α_2 - values are given in column 9 of Table-1. With level bed ($\beta = 0^0$), α_2 was found to be 2.73 for 3:1 side splay and 6 for 0:1 splay. With adverse slope, α_2 was 1.17 for 3:1 side splay and 1.30 for 1:1 splay, α_2 reduced with reduction in flow. Downstream flow pattern for level and advently sloping expansion floor are shown in Figs. 2, 3 and 4 for side splays corresponding to 1:1, 2:1 and 3:1 respectively. Separation was completely eliminated by providing adverse slope computed by equations 9 and 10.



(a) Q = 20 l/SEC, LEVEL BED, (β = 0°)

(b) Q = 20 l/SEC, WITH BED SLOPE (β = 16.6°)

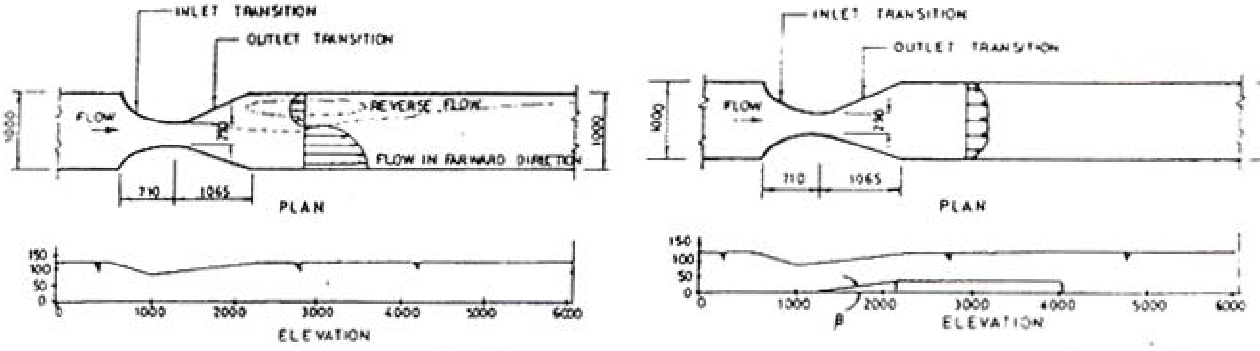
FIG. 2. DOWNSTREAM FLOW PATTERN WITH LEVEL AND ADVERSELY SLOPING BED (SIDE SPLAY 1:1)



(a) Q = 20 l / SEC, LEVEL BED(β.0°)

(b) Q = 20 l / SEC, LEVEL BED(β.8.48°)

FIG. 3. DOWNSTREAM FLOW PATTERN WITH LEVEL AND ADVERSELY SLOPING BED (SIDE SPLAY 2:1)



(a) Q = 20 l / SEC, LEVEL BED(β.0°)

(b) Q = 20 l / SEC, LEVEL BED(β.5.67°)

FIG. 4. DOWNSTREAM FLOW PATTERN WITH LEVEL AND ADVERSELY SLOPING BED (SIDE SPLAY 3:1)

CONCLUSIONS

i Conventional type of flow meters have several limitations e.g. afflux, silting, loss in depth-discharge relation, uncertainty of C_d, low modular limit, energy dissipation requirements and poor flow conditions in the tail channel when conventional types of outlet transition are provided.

ii Almost all the problems of the conventional meters were overcome in the improved flow meter studied herein.

iii Jaeger's transition at the inlet, having an average side splay of 2:1, was found to be quite efficient.

iv C_d value of the meter was found to be varying between 1.67 to 1.73 $m^{1/2}$/sec. C_d is not affected by geometry of flow meter downstream of control section.

v The flow meter has high modular limit (varying from 0.9 to 98).

vi Efficiency η_o of the expansive outlet transition with straight side walls was extremely poor when the floor of expansion was level. Velocity distribution was nonuniform and large scale separation occurred in all the flows.

vii Performance of the expansion improved remarkably with provision of adverse slope to expansion floor as per equation (9) and (10) by Mazumder (1994). There was sharp rise in the hydraulic efficiency. Velocity distribution was highly uniform resulting in normal value of α_2. The flow in the tail channel was smooth and free from any separation and eddies.

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REFERENCES

Ackers, P., White, W. R., Perkins, J. A. and Harrison, A. J. M. (1978). Weirs and Flumes for Flow Measurement. John Wiley & Sons, New York.

Bos, M. G. (1975). Discharge Measurement Structures. Oxford and IBH Publishing Co., New Delhi.

Chaturvedi, R. S. (1963). Expansive Sub-Critical Flow in Open Channel Expansions. Journal of the Institution of Engineers (India). Vol. 43, No. 9, pt c15, May, pp. 447.

Garde, R. J. and Nasta, C. F. (1980). Sub-Critical Flow in Rigid Bed Open Channel Expansions. Proc., ASCE, Journal of Hyd. Div., Vol. 26, pp. 49 - 53.

Hinds, J. (1928). Hydraulic Design of Flume and Siphon Transition. Trans. A.S.C.E., Vol. 92, pp. 1423 - 1459.

Jaeger, C. (1956). Engineering Fluid Mechanics. Blackie and Sons, First Edition, pp. 78 - 79.

King, W. H. (1954). Hand Book of Hydraulics. Revised by Ernest F. Barter, McGraw Hill Book Company, New York.

Mazumder, S. K. (1977). Design of Transition in Open Channel Sub-Critical Flow. Proc. XVII Congress of IAHR, Karlshruhe, W. Germany, Aug., pp. 422 - 438.

Mazumder, S. K. (1981). Studies of Modular Limit of Critical Flow Meters. Proc. of XIXth Congress of IAHR, held at New Delhi.

Mazumder, S. K. and Darde, P. N. (1994). Control of Separation in Open Channel Sub-Critical Expansion with Adverse Bed Slope. Proc. of XIth Congress of APD-IAHR, Vol. - II, 24 - 26th August, Singapore, pp. 431 - 438.

Parashall, R. L. (1950). Measuring Water in Irrigation Channels with Parshall Flumes and Small Weirs. U.S. Soil Conservation Service, Circular 843, May.

Ranga Raju, K. G. (1993). Flow in Open Channels. Tata McGraw Hill Publishing Co., New Delhi.

Skogerboe, G. V. and Hyatt, M. L. (1967). Rectangular Cut Throat Flow Measuring Flumes. Proc., A.S.C.E., JID, No. 93, IR4, December.

Subramanya, K. (1986). Flow in Open Channels. Tata McGraw Hill Publishing Co., New Delhi.

Swamee, P. K. and Basak, B. C. (1992). Design of Rectangular Expansive Transitions in Open Channel Sub-Critical Flow. JID Engineering, Vol. 118, No. 1, Jan-Feb., pp. 61 - 73.

Vittal, N. and Chiranjeevi, V. V. (1983). Open Channel Transitions - Rational Method of Design. JHE, Proc, A.S.C.E., Jan.

NOTATIONS

A = Cross sectional area of flow at the exit of expanding transition
B = Width at the control section of the flow meter
B_1 = Width of channel upstream of the flow meter
B_2 = Width of channel downstream
C_d = Coefficient of discharge
C_i = Energy loss coefficient at the inlet
C_o = Energy loss coefficient at the outlet
dA = Elementary area
E_1 = Specific energy at the upstream section
E_c = Specific critical energy at the control section
E_{1max} = Specific energy at the upstream section for maximum discharge
E_{1min} = Specific energy at the upstream section for minimum discharge
F_2 = Froude number of flow downstream of expansion
g = Acceleration due to gravity
H_c = Energy head above the crest of the flow meter
$h_{L,i}$ = Head loss between upstream and control section
$h_{L,o}$ = Head loss between control and downstream section
u = Velocity through elementary area
V = Mean velocity of flow
V_1 = Mean velocity of flow at the upstream section
V_2 = Mean velocity of flow at the downstream section
V_c = Mean velocity of flow at the control section
Y = Depth of water
Y_1 = Depth of water at the upstream section
Y_2 = Depth of water at the downstream section
Y_c = Depth of water at the control section
Δ = Maximum height of hump at control section
$\Delta y_{(1-c)}$ = Difference in water levels between the upstream and the control section
$\Delta y_{(c-2)}$ = Difference in water levels between the downstream and the control section
Y_{1max} = Depth of water at the upstream section corresponding to maximum discharge
Y_{1min} = Depth of water at the upstream section corresponding to minimum discharge
β = Adverse bed slope
δ = y_c / y_2
λ = B_1 / B
η_o = Efficiency of outlet transition
η_i = Efficiency of inlet transition
α_2 = Coriolis coefficient at the exit of the expansion

TABLE-1

PERFORMANCE OF FLOW METER WITH LEVEL AND ADVERSELY SLOPING EXPANSION FLOOR

Expt. No. (1)	Q (LPS) (2)	Side Splay Expn. (3)	β^o (4)	C_d ($m^{1/2}$/sec) (5)	Modular Limit (6)	$\%\eta_i$ (7)	$\%\eta_o$ (8)	α_2 (9)	Remarks (10)
1	20	0:1	0	1.67	0.90	86	28	6.00	Separation occurred on both sides. Large eddies on both sides of tail channel.
2	10	0:1	0	1.68	0.91	87	39	-	- Do -
3	5	0:1	0	1.72	0.91	88	43	-	- Do -
4	20	1:1	0	1.67	0.92	86	31	4.05	- Do -
5	10	1:1	0	1.69	0.92	86	40	-	- Do -
6	5	1:1	0	1.69	0.92	88	49	-	- Do -
7	20	2:1	0	1.70	0.96	87	31	3.26	Separation occurs on one side only. Large eddy on one side of tail channel.
8	10	2:1	0	1.70	0.96	88	40	-	- Do -
9	5	2:1	0	1.73	0.96	89	50	-	- Do -
10	20	3:1	0	1.67	0.98	88	33	2.73	- Do -
11	10	3:1	0	1.69	0.98	90	42	-	- Do -
12	5	3:1	0	1.73	0.98	94	54	-	- Do -
13	20	1:1	16.6	1.67	0.92	87	90	1.30	Two symmetric small eddies confined within expansion reach. Uniform flow in tail channel
14	10	1:1	16.6	1.69	0.92	89	91	-	- Do -
15	5	1:1	16.6	1.69	0.92	93	99	-	- Do -
16	20	2:1	8.48	1.70	0.96	88	91	1.23	No separation, no eddy, flow in tail channel smooth and uniform
17	10	2:1	8.48	1.70	0.96	92	93	-	- Do -
18	5	2:1	8.48	1.73	0.96	98	99	-	- Do -
19	20	3:1	5.67	1.67	0.98	90	93	1.17	- Do -
20	10	3:1	5.67	1.69	0.98	95	94	-	- Do -
21	5	3:1	5.67	1.73	0.98	99	99	-	- Do -